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AFIT/GCA/LSG/92S-5

LIFE-CYCLE COSTS OF ALTERNATIVE ICBM SECOND STAGE DESIGNS

THESIS

Brian D. Joyce, First Lieutenant, USAF
Patrick E. Poppert, Captain, USAF

AFIT/GCA/LSG/92S-5

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THESIS

Presented to the Faculty of the School of Systems

and Logistics of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Cost Analysis

Brian D. Joyce, B.S.
First Lieutenant, USAF

and

Patrick E. Poppert, CIA, M.B.A.
Captain, USAF

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Preface

The purpose of this study was twofold. The primary objective of our research was to develop and report life-cycle cost estimates for new second stage ICBM booster designs to Phillips Laboratory. Our second objective (perhaps of equal or greater importance as the first), was to provide the users of these estimates with a taste of what exactly is involved in life-cycle costs, the cost estimating process, and factors that influence these items.

Life-cycle cost estimates were requested to supplement separate engineering and research efforts of both Phillips Laboratory and graduate students at the School of Engineering, Air Force Institute of Technology. These parallel, yet independent efforts were aimed at the same objective: enhancing our ballistic missile technology base by addressing the anticipated need for modernization of an aging Minuteman III ICBM fleet. Our involvement in these efforts included extensive review of life-cycle cost and cost modeling literature; interviews with government cost analysis experts; identification and evaluation of existing cost models for suitability; and, processing of selected Phillips Laboratory and AFIT engineering booster design parameters to arrive at our estimates.

All too often in the past, the "cost" portions of major program cost-benefit analyses were delineated solely by the initial weapons system purchase price. In an age of program

life extensions (or "stretchouts") and high-tech, multi-billion dollar weapon system acquisitions, we can no longer afford to overlook costs that represent the rest of the "package deal." Hidden expenditures such as future operations and support outlays now make up a major portion of the typical defense program's total cost, and the DoD budget! With the Air Force budget shrinking everyday, all proposed acquisitions must be approached from the life-cycle cost perspective.

We would like to thank both our thesis advisors, Professor Ralph Liebhaber and Lieutenant Colonel John Shishoff, for their advice, encouragement and technical guidance on our research. We would also like to thank those involved with the 1991 Small ICBM Operations and Support cost estimate. Your assistance with the O&S portion of our estimate was invaluable. Finally, we would like to express sincere gratitude to our wives, Gail and Teresa, for their enduring patience and support - we couldn't have done it without you.

This thesis is dedicated to the memory of Captain Jeffrey J. Olson, who gave his life that others may live.

Brian D. Joyce

Patrick E. Poppert

Table of Contents

Page

List of Figures

List of Tables

List of Equations

AFIT/GCA/LSG/92S-5

Abstract

This study analyzes proposed ICBM modifications from a life-cycle cost perspective. The proposals call for replacement of the Minuteman III second and third stage motors through a new, high performance single stage, without compromise in missile performance capabilities. This project was initiated by the Phillips Laboratory Applications Engineering Division. To expedite research and provide a basis for comparison, Phillips Laboratory also tasked graduate engineering students from the Air Force Institute of Technology (AFIT) School of Systems with a parallel design project. As graduate students of the AFIT School of Logistics, the authors of this study were solicited to provide life-cycle cost estimates for both alternatives.

The Solid Technology Assessment and Cost Evaluation Model (STACEM) was selected to derive the estimates for program design, development, test and evaluation (DDT&E), and production costs. The Strategic Missile Cost Estimating (STRAMICE) model was chosen to develop one operations and support (O&S) cost estimate for both designs. Estimated DDT&E and production costs for the Phillips Laboratory design were \$990.0 million. The same costs for the AFIT design were \$743.3 million. The twenty year O&S estimate under either

design was $10,029.0 million; a savings of approximately $69.8 million over the status quo.

LIFE-CYCLE COSTS OF ALTERNATIVE ICBM SECOND STAGE DESIGNS

Chapter I
Introduction

General Issue

The Annual Report of the Secretary of Defense is an assessment of U.S. military posture as it relates to international developments and perceived threats to national security. For forty-six years, the Soviet threat has been the central focus of this report. However, dramatic changes in the Soviet political process and economy over the last year have greatly altered the Department of Defense's stance. As Secretary of Defense Richard Cheney notes in the FY 1992 DoD Annual Report, ". . .the threat of a short-warning, global war starting in Europe is now less likely than at any time in the last 45 years" (11:vii). The secretary is careful to note that the threat is not completely gone, but the potential for nuclear or significant conventional aggression on the part of the former Soviet Union is almost nonexistent (37:214).

With this "thaw" in the Cold War, a number of problems and challenges face the Air Force. Specifically, dissolution of the Soviet nuclear and conventional threat has sparked a variety of reactions in the DoD, most of which center around force reduction issues. As our political and military leaders contemplate how these reductions will be orchestrated, emphasis on a "quality force" is renewed.

At Edwards AFB, Phillips Laboratory is addressing the quality force concern through ballistic missile research and technology improvements. Specifically, they have anticipated the need to down-scale and modernize an aging Minuteman Inter-Continental Ballistic Missile (ICBM) fleet with smaller, enhanced performance missiles. Consequently, the laboratory has engaged in development of a new ICBM second stage design that incorporates state of the art technology.

To expedite research and provide a basis of comparison, Phillips Laboratory solicited the aid of Air Force Institute of Technology (AFIT) School of Systems graduate engineering students. These students were tasked with developing an independent booster design given parallel constraints. The combined efforts are directed at providing senior DoD leaders with a timely solution to proposed draw-downs in nuclear forces and reductions in military spending while still maintaining an effective nuclear deterrent.

Specific Problem

When a system is proposed for Air Force acquisition, life-cycle costs become a key element of the concept approval and design selection processes. Because defense funding is limited and today's weapons system programs span many years at billions of dollars, estimates of life-cycle costs are necessary to determine the amount and type of equipment the Air Force can procure to fill a given mission need.

Essentially, life-cycle costs provide the "whole systems" view from the financial perspective. As such, they are the focus of formal cost-benefit analyses. Given competing ideas or bids for the same mission need, life-cycle costs play a major part, if not the primary role in final selection. They also become the basis for continued program support and funding after selection and well into the program's life. For these reasons, a proposed concept or acquisition is no longer complete without these figures.

To produce a complete research package that facilitates comparison of alternate designs and assessment of program cost feasibility, Phillips Laboratory required life-cycle cost estimates for the second stage booster designs under review. As graduate cost analysis students, we were tasked with this effort and we provided the needed estimates through our thesis research requirements.

Investigative Questions

To develop life-cycle cost estimates for the alternative booster designs, we determined the following questions must be addressed:

1. Under common life-cycle costing practices, what program phases comprise a ballistic missile booster life-cycle?

2. For each phase of the booster life-cycle, what are the major factors (design and performance characteristics, parameters and assumptions) that traditionally affect program life-cycle costs in aggregate? What cost drivers generally address these factors?

3. Are innovative booster technologies involved in the Phillips Laboratory and AFIT School of Systems Engineering booster designs? If so, do these technologies represent new factors requiring consideration of additional/substitute cost drivers?

4. What existing cost models are available to support life-cycle cost estimating for the two booster designs?

5. If existing cost models cannot support all of our cost estimating efforts, what other quantitative methods or qualitative sources of cost estimating are available to support booster cost estimating?

6. What are the values for the final booster design specifications and assumptions necessary to generate our life-cycle cost estimate (i.e., independent variable values)?

Scope/Limitations

Our objective was to develop life-cycle cost estimates for both the Phillips Laboratory and AFIT engineering group's second stage booster designs. In deriving our estimates, we applied existing cost models where possible, making adjustments as needed. In the absence of applicable cost models, we planned to develop our own. Qualitative (expert opinion) and quantitative (statistical) techniques were used for cost model evaluation and adjustments. Because historical data on ballistic missile programs was limited, data consideration was not restricted through sampling. All available solid rocket motor data on United States ballistic missile programs was considered for review. Any assumptions employed in our cost modeling efforts were those of the ultimate system user as interpreted by Phillips Laboratory. Our research was performed during the period January through August 1992.

Definitions

Life-Cycle Costs. Life-cycle costs are total estimated expenditures for a system, from cradle to grave. "The life cycle cost of an item-its total cost at the end of its lifetime-includes all expenses for research and development, production, modification, transportation, introduction of the item into inventory, new facilities, operation, support, maintenance, disposal, and any other costs of ownership, less any salvage revenue at the end of its lifetime" (61:9). Figure 1-1 emphasizes the fact that there is more to weapon system program costs than the initial acquisition outlays.

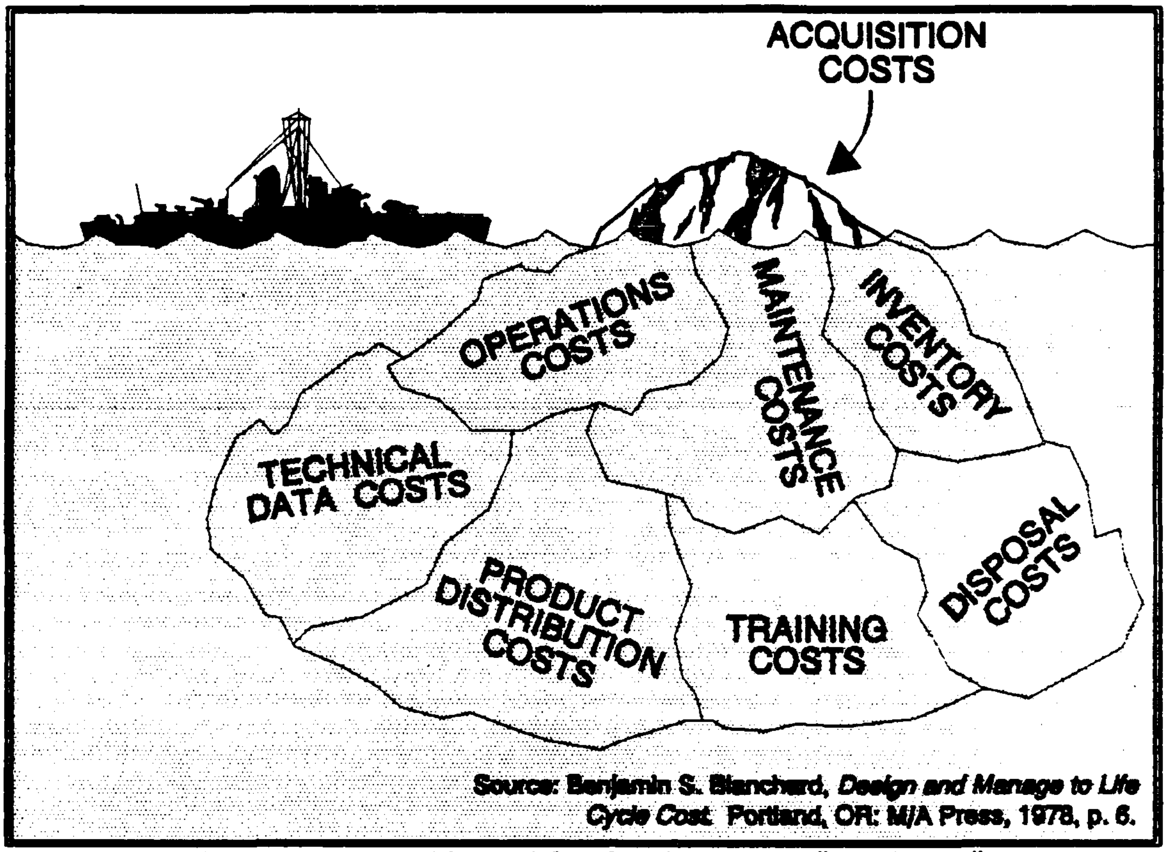


Figure 1-1. The Life-Cycle Cost "Iceberg"

Major Factors. In life-cycle costing, major factors are predictable factors that influence program costs. These factors may be process oriented (e.g., capital, labor, material, organizational complexity, management), product oriented (e.g., the product itself, performance characteristics, operational use, logistics support), and environmental programmatic (e.g., competition, funding, type of contract, schedule, program stability) (44).

Cost Drivers. Cost drivers are a means of quantifying major factors. They are design and program characteristics that capture the influence of one or more major factors on program costs. For example, labor is a major factor and its influence on program cost may be accounted for through production quantities (the cost driver).

Cost Modeling. Cost modeling is a method for deriving life-cycle costs (or components of these costs) through quantitative or qualitative means, or some combination of the two.

(1) Quantitative means are formal, objective statistically-based techniques such as regression analysis.

(2) Qualitative means are subjective approaches such as expert opinion and the Delphi technique.

Cost Model. Cost models are the end result of cost modeling. Their purpose is to provide cost estimates for the subject area over the relevant range, given established constraints and underlying assumptions. Generally, these models take the form of a dependent variable (the cost estimate) and one or more independent variables (the cost drivers).

Second Stage Booster. Boosters are the rocket motors used to propel ballistic missiles. Some missiles have two or more boosters that are "stacked," firing in sequential order

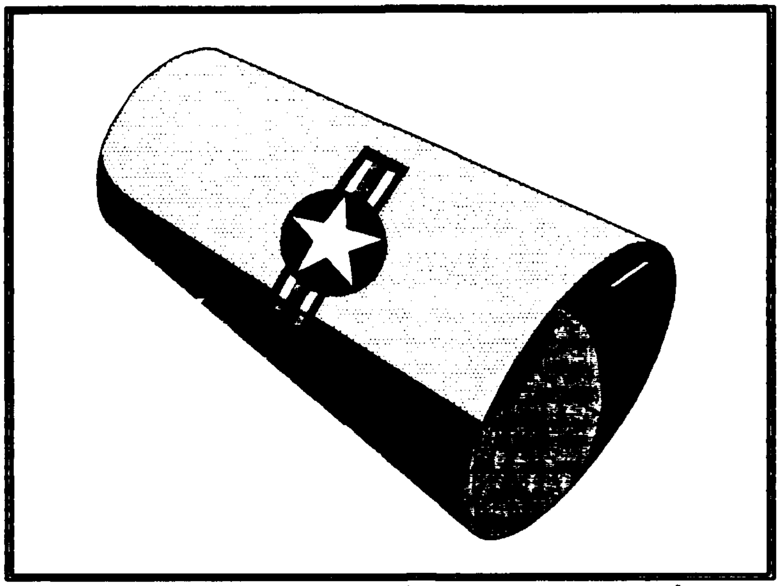


Figure 1-2. Phillips Laboratory's
Second Stage Booster Concept

from bottom to top; as one booster is expended and separated from the missile, the next one lights. On these missiles, the boosters are referred to as "stages," numbered in their sequential firing order. For our research, we are concerned with the life-cycle costs for the second (final) stage of an ICBM, as depicted in Figure 1-2.

<u>STACEM</u>. Solid Technology Assessment and Cost Evaluation Model (STACEM) is a cost model software package developed by Booz-Allen & Hamilton Incorporated, under government contract. It is a general purpose cost model designed to develop cost estimates for ballistic missile systems incorporating solid rocket motors (as opposed to liquid fuel motors).

Background

Phillips Laboratory is engaged in developing a new second stage ICBM booster. Presently, they are operating under the assumption that their design may replace the existing Minuteman III second and third stages, with the first stage, guidance package and payload remaining unchanged. This scenario is illustrated in Figure 1-3. The lab's goal is to further advance booster technology for an anticipated future need. This concept of "technology insertion" is a major function for Air Force laboratories. To make use of all available resources, the Phillips Laboratory has solicited the efforts of AFIT engineering graduate students via their thesis project. This arrangement was established as a low cost, independent approach to pushing the same technological advances. Both groups will be operating under the same assumptions and constraints, filling the same mission need and capability.

In the not-too-distant past, purchase price of individual weapons systems was the primary focus of government research and development (R&D) and acquisition agencies. With government budgets becoming tighter each year, the focus has shifted to ownership costs (logistics, operations and maintenance) since these costs are often much greater than the initial procurement outlays (61:1). In fact, in 1990 these costs represented the largest single category (30 percent) of the $289.8 billion Department of Defense budget (63:124). Because low initial purchase prices generally translate to

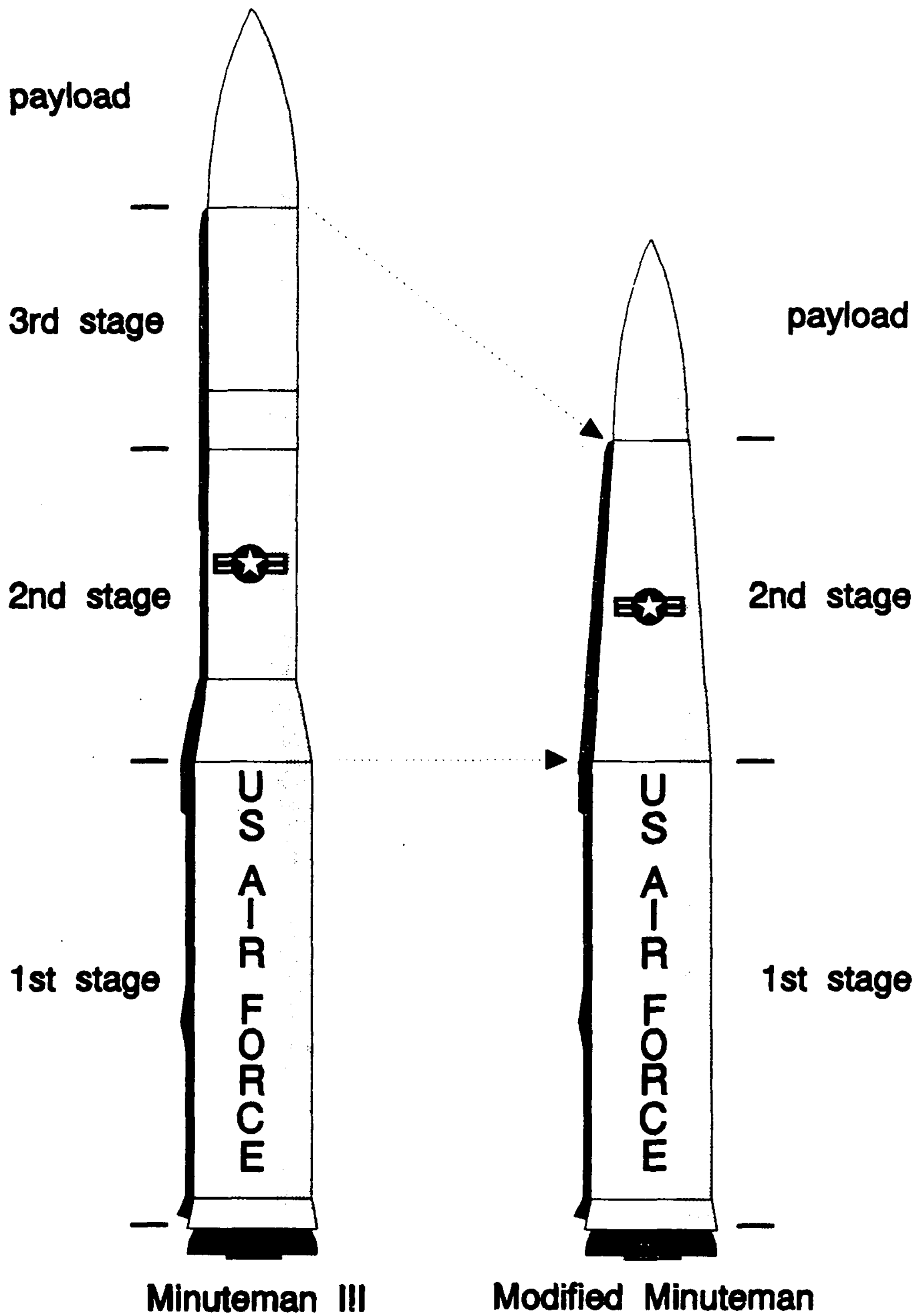


Figure 1-3. Potential Second Stage Booster Design Application

higher operation and support costs, program life-cycle costs have become the only relative basis for cost comparison of competing programs (61:1-2).

Phillips Laboratory and the AFIT engineering students are developing competing designs. As such, estimated life-cycle costs will be critical when their end-products are evaluated. We agreed to address this requirement. STACEM was presented to us by the laboratory as a suggested medium for developing our estimates.

Research Overview

As state previously, the primary objective of our effort is to provide Phillips Laboratory with comprehensive ICBM life-cycle cost estimates for comparison of their booster design with that of the graduate students in the AFIT School of Systems. Direction for the lab's research, the need to push ICBM technology, and the importance of integrated life-cycle cost estimates have been outlined in this chapter.

Chapter two presents a detailed background on the guidance driving Phillips Laboratory's research. It also provides an extensive summary of current literature on life-cycle costs and what they encompass; cost modeling and how estimates are developed; and, uncontrollable factors that impact cost estimates, such as learning curves and inflation. Finally, this chapter addresses current cost models that may prove useful in our cost estimating efforts.

Chapter three outlines our plan of action for cost model evaluation and how information and data will be obtained, analyzed and used to develop our estimates. Chapter four outlines the details of our actual cost model and data analyses, and concludes with a summary of the models, procedures, and inputs (parameters and assumptions) that will be used to develop our life-cycle cost estimates. Finally, chapter five presents our life-cycle cost estimates for the two booster designs as well as the underlying assumptions and limitations on their use.

Chapter Summary

We identified the anticipated need for a modernized ICBM fleet as the general issue. Our objective is development of life-cycle cost estimates for the competing second stage ICBM booster designs that will meet this need. We established several investigative questions that must be answered to arrive at these estimates. The scope of our research was limited to available ballistic missile data, quantitative and qualitative cost modeling methods, and the assumptions and constraints imposed by Phillips Laboratory. Definitions of key terms were presented and a background of our working relationship with the laboratory and the AFIT engineering group was provided. Finally, a brief overview of our planned research and analyses was presented.

Chapter II
Literature Review

Chapter Overview

This chapter describes the Air Force's current ICBM workhorse, Minuteman III. It then outlines new customer (user) requirements as presented to Phillips Laboratory. Chapter II also describes life-cycle costs and the components that make up these costs. Next, cost estimating is defined and the general approaches to cost modeling are discussed. Finally, the chapter concludes with information about STACEM (the booster life-cycle cost model suggested to us by Phillips Laboratory), the model's development, and its validation.

Minuteman III: Current ICBM Mainstay

Description. Minuteman III is designated LGM-30G for "Launched from silo, directed to Ground target, Missile" (60:242). This silo-based missile is a three stage, solid fuel, intercontinental range, strategic nuclear weapons delivery platform. It is capable of boosting a 2400 pound, MIRVed (Multiple, Independently targetable Re-entry Vehicles) payload a distance of 7,000 to 8,000 nautical miles (15:Vol 1,116).

History. The Minuteman family has been active since 1962 with the first Minuteman III entering service in 1970 (15:Vol 1,118). Initial missile development began in 1958 under the

Minuteman A program, with Boeing Aerospace Company as the prime contractor (45:113). In the midst of a growing "Missile Gap" between Soviet and American nuclear weapons delivery capabilities, United States military planners foresaw the need for a ". . . smaller and simpler second-generation ICBM using solid propellant" (26:219). In 1959, chronic test flight failures with the Air Force's front line ICBM (Atlas), reinforced this position (45:115).

The first Minuteman ICBM went on alert in October 1962 as the United State's only three stage, solid propellant ICBM (15:Vol 1,118). Almost immediately, development of an upgraded Minuteman II began, with the first being deployed in October 1965 (15:Vol 1,118). In 1966, Minuteman III development was underway, and the first wing was activated in December 1970 (15:Vol 1,118). The upgrade to Minuteman II involved improvements to the guidance system and increased range and payload capability (38:LGM-30F Minuteman II). A larger, more powerful second stage was included in this design (60:246-247). The Minuteman III upgrade featured a larger third stage and a liquid fuel fourth "stage," or post-boost vehicle for the new MIRV platform; it was the first in the Minuteman series to facilitate multiple warheads (38:LGM-30G Minuteman III). The same first stage booster has been used throughout the Minuteman program life.

<u>Specifications</u>. The Minuteman III gross weight at launch is 77,900 pounds (15:Vol 1,116). The entire missile measures

59 feet, 10 inches in length (26:219). Its boosters generate a maximum speed of 15,000+ mph (Mach 19.7) at motor burn-out, and the payload ceiling is 700 miles (15:Vol 1,116). The missile incorporates an all inertial, gimballed guidance system (INS-20) developed by Rockwell International (15:Vol 1,116). According to the 1990 edition of *Jane's Strategic Weapon Systems*, the Minuteman III payload is comprised of three W-78/MK12A, 335 kiloton, MIRVed nuclear warheads, each having an accuracy of 120 meters Circle Error Probable (CEP) (38:LGM-30G Minuteman III).

The Minuteman III's first stage is a solid rocket motor (SRM) developed my Thiokol Chemical Corporation. Designated the TU-120 (M55E), this stage can deliver 200,000 pounds of thrust for a period of 60 seconds (26:219). It measures 66 inches in diameter and is maneuvered by four gimbaled nozzles (15:Vol 1,116).

The second stage SRM for the Minuteman III (SR19) was developed by Aerojet General (26:219). This stage is 52 inches in diameter (15:Vol 1,116). It can deliver 60,000 pounds of thrust and it incorporates liquid-injection for thrust-vector control since the nozzle is fixed (26:219).

The Minuteman III third stage SRM was developed by the Thiokol/Aerojet team (26:219). It also measures 52 inches in diameter, and it is capable of delivering 34,876 pounds of thrust (15:Vol 1,116; 26:219). To provide ". . . finer [directional] control than the previous system of four moveable nozzles," the third stage includes a fixed nozzle with liquid-injection thrust-vector control (38:LGM-30G Minuteman III).

The post-boost vehicle ("fourth stage") incorporates a liquid fuel motor. Directional control is provided by six pitch/yaw motors and four roll motors (38:LGM-30G Minuteman III). The integrated guidance system for this stage controls these motors as well as the re-entry vehicle and penetration aid releases (38:LGM-30G Minuteman III). This stage houses the missile's payload: warheads (re-entry vehicles), chaff, decoys and other defense penetrating measures (26:219).

Program and Cost Data. Since 1968, 840 Minuteman III ICBMs have been produced (49:3-6). Five hundred and fifty of these missiles were deployed in silos at FE Warren, Grand Forks, Malstrom and Minot Air Force Bases (38:LGM-30G Minuteman III). The remaining 290 missiles were procured for spares, R&D, and Follow-on Test and Evaluation (FOT&E) launches. Currently, 500 Minuteman IIIs are deployed; silos for fifty of the missiles were relinquished to facilitate MX Peacekeeper activation in 1988 (38:LGM-118 Peacekeeper).

Minuteman III production was canceled late in 1977 (26:219). Production rate at that time was twelve per month, and the unit "flyaway cost" was $4.842 million per missile in FY 1977 dollars (48:1-6;15:Vol 1,119). "Flyaway cost is the average cost for one fully equipped missile based upon the quantity anticipated or purchased during the life of the program" (48:E-2). As of 1982, annual operating and support costs for the 550 deployed missiles were $345 million in FY 1982 dollars (15:Vol 1,119). From program inception through 1972, Minuteman III procurement costs totaled $3,652.4 million in "then year" dollars (48:2-54). Between 1973 and 1983, these costs summed to $3,103.3 billion, tapering off to a mere $81.8 million (mostly RDT&E) in 1983 (48:2-54). For the three years beginning with 1980, annual procurement costs in millions were $144.5, $196.0 and $185.7 (48:2-54).

Although missile production ended in 1977, DoD plans in 1990 were to maintain the Minuteman III fleet into the year 2008 (38:LGM-30G Minuteman III). Continual upgrades in the silos, guidance software packages and the Command Data Buffer System support these plans (26:219). To effectively stretch the ICBM program life and still monitor system performance, military planners proposed reducing the number of annual follow-on test and evaluation (FOT&E) flight tests from the original projection of seven to four (38:LGM-30G Minuteman III).

New User Requirements

As an element of the new Air Force Material Command (AFMC), Phillips Laboratory shares the same goals and objectives. Two of these goals are satisfaction of customer needs (in war and peace), and "sustained technological superiority" (41:3). A key objective for meeting these goals is the leveraged use of ". . . the science and technology of other defense and government labs, allies, academia and industry" (41:3). Phillips Laboratory has elected to address this objective by soliciting the aid of Air Force Institute of Technology graduate engineering and logistics students in their current endeavor: development of a new ICBM second stage design that incorporates state of the art technology.

Phillips Lab's primary customers are the Department of Defense, Air Force Material Command, Air Combat Command (ACC), the Ballistic Missile Organization (BMO) and the Strategic Missile Technical Oversight Committee (SMTOC) (55:1). As a research facility, the lab's work is guided by the needs of these users. Presently user needs, as interpreted by the lab, include (1) evaluation of life extension technologies and enhanced performance capabilities for existing ICBMs, (2) maintenance of a strong ICBM technology base through development of new designs, and (3) maximum reuse of existing ICBM materials in these new designs (55:1).

In January 1992, ACC (then SAC) levied a requirement for ". . . an intercontinental strategic weapon delivery system beyond the year 2010" (16:1). According to their draft Mission Need Statement, this system must be affordable in terms of initial procurement *and* low operations and support costs (16:attachment 1). The focus of research, as noted in the draft, should be readiness, response rate (time-on-target), survivability, reliability and maintainability (16:attachment 1). The draft Mission Need Statement suggests exploration of the following potential alternatives: (1) a Minuteman III life extension program, (2) redesign of the

Small ICBM, and (3) development of an all new "Next Generation Strategic Weapon System" (16:attachment 1).

Additional SAC expectations are outlined in Lt Col Bailey's "The SAC Perspective on ICBM Programs." In this summary draft report, Lt Col Bailey recognizes the need for downscaling of our nuclear forces based on peace in Europe, the Strategic Arms Reduction Treaty (START) and the fall of Soviet Communism (2:1). He also presents the SAC, AFLC and BMO requirement for a Minuteman III life extension program as well as ". . . continued development of Small ICBM as a hedge for our uncertain future" (2:2). From a cost perspective, the report leans toward the Minuteman refurbishment concept (less than $7 billion for another 25 years of service) should the two programs be pitted against each other (2:4).

To address concerns raised in the SAC draft Mission Need Statement, the Strategic Missile Technical Oversight Center provided Phillips Laboratory detailed requirements for their second stage ICBM research (the propulsion component of the overall advanced ICBM concept exploration). These requirements center around a sustained ICBM technology base, enhanced performance capabilities, reliability, extended service lives, and consideration of Minuteman III upgrade possibilities (64). Specific requirements include cost reduction technology studies to lower operations and support expenses; low cost component and rocket motor developments to address the initial procurement affordability concern; commercial technology infusion to maintain a strong industrial base; consideration of Minuteman motor life extension programs to make economical use of existing assets; and a versatile propulsion design that meets anticipated mission needs and incorporates environmental considerations (64).

The Kaman Sciences report, *A New Approach to High Performance ICBM Design*, has been a guiding force in the direction of Phillips Laboratory research (55). Developed under government contract, this report describes a ". . . highly stable, low drag, two-stage booster which is lighter, faster burning, more reliable, and less expensive than an equivalent, conventionally designed, three-stage missile" (36:40). According to this report, substitution of an unconventional conical upper (second) stage for the traditional cylindrical shaped motor would greatly reduce drag, structural loads, and missile weight while increasing staging stability (36:40). Additionally, since current ICBMs incorporate a three stage design, replacing the two upper stages with the one conical motor would improve system reliability and reduce procurement costs nearly twenty percent (36:40).

The Kaman report suggests a fixed, enclosed nozzle on the conical second stage rather than the standard exposed nozzle. This concept is contrasted with the conventional Minuteman ICBM design in Figure 2-1. Like the Minuteman III second and third stage nozzles, hot gas injection is used to provide the thrust vector control normally handled by a cumbersome gimbal package. This feature reduces cost through added reliability

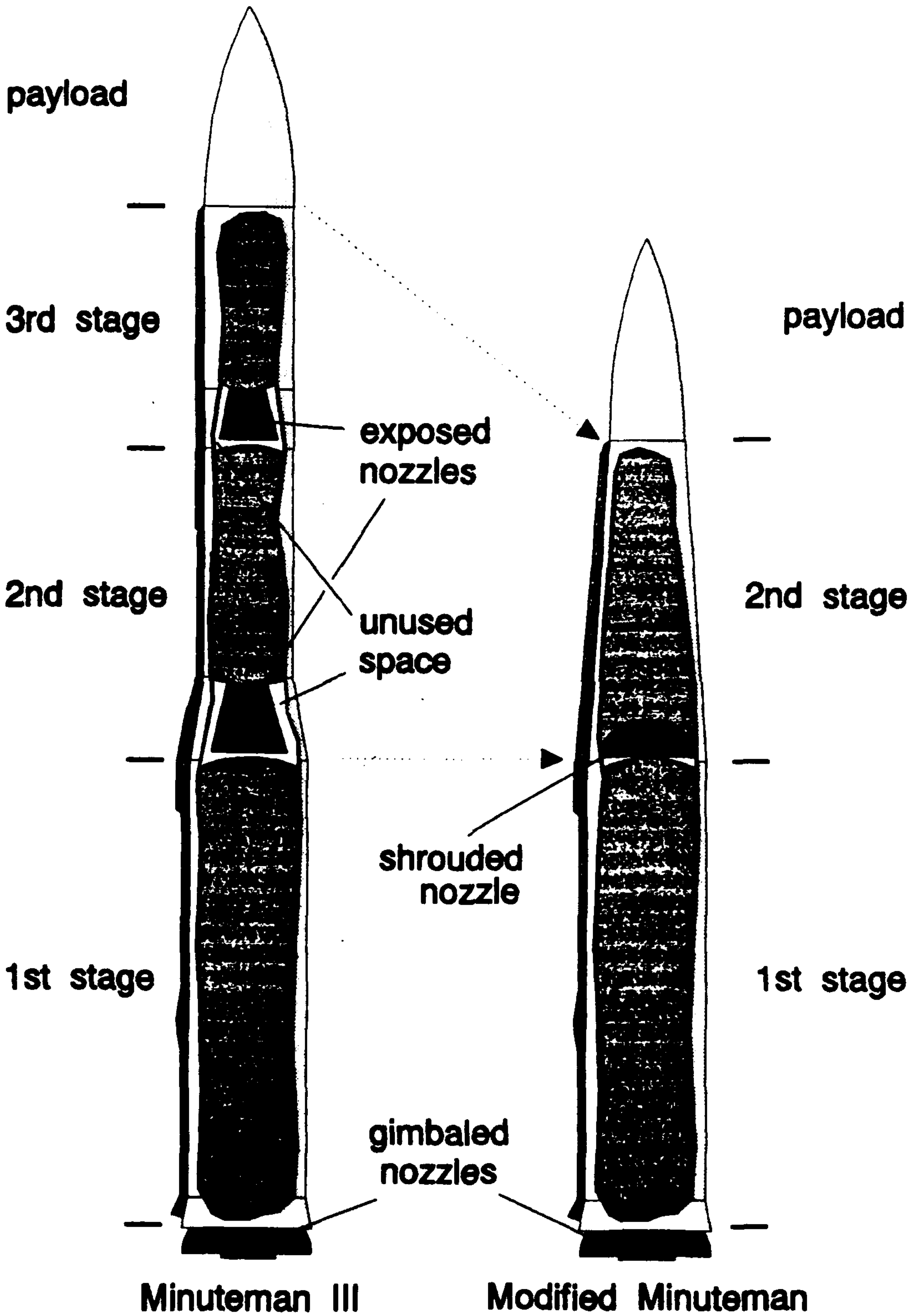
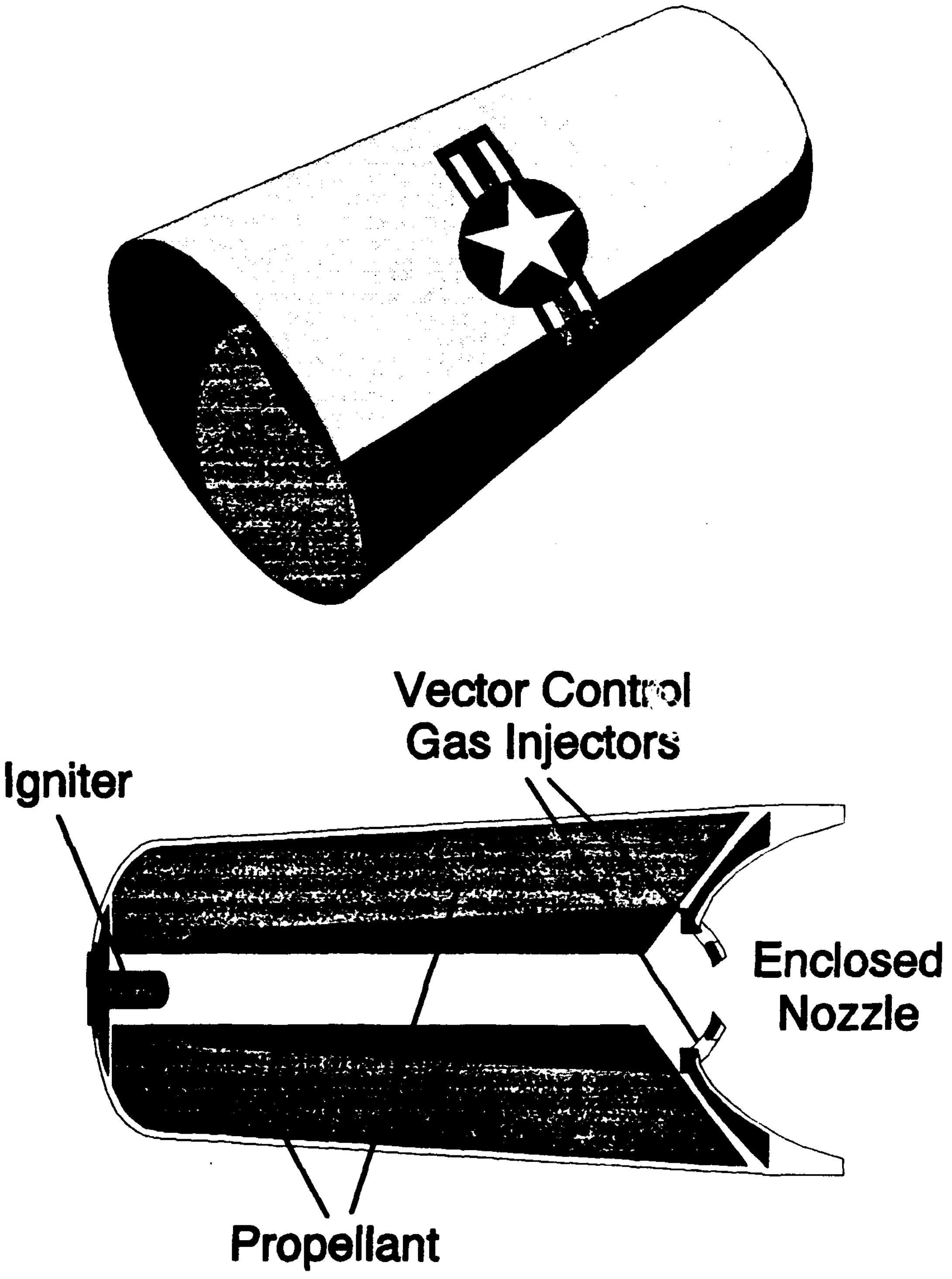


Figure 2-1. Cutaway Drawing of Minuteman and Conical Second Stage Booster Design

(fewer moving parts) and decreased weight (36:40). Unlike any of the Minuteman III stages, the proposed booster casing shrouds the nozzle, effectively providing more propellant space. More importantly though, this attribute and the conical shape enhance missile stability in flight by bringing the booster's center of thrust closer to its center of gravity. The conical shape of the propellant also facilitates a fast burn time, thereby diminishing the ". . . capability of the defense to target and destroy the boosters" (36:1). In short, the Kaman report proposes a design that is capable of the same throw weight and range of conventional ICBMs, at a lower system weight and cost. The influence of the Kaman Sciences report on Phillips Lab's efforts is evident in Figure 2-2.

The conclusion of the Kaman Sciences report notes, "The entire design approach [presented] is based on today's technology. Further enhancements in performance can therefore be expected as new technologies become available" (36:1). This view is held by Phillips Laboratory personnel as well. Their objective is to push technologies that capitalize on the findings of the Kaman Sciences Corporation.

In summary, Phillips Laboratory has anticipated a need for a new ICBM second stage booster design. This anticipated need was driven by their users' projected requirements. However, the uncertainty of future military funding and geopolitical events has precluded the lab's customers from providing specific direction at this time. As such, the lab's



Source: Phillips Laboratory

Figure 2-2. Conical Booster Design Under Review at Phillips Laboratory efforts may be considered proactive; paralleling, rather than reacting to the users' first step in the DoD acquisition process ("pre-milestone 0," as noted in Figure 2-3). Consequently, Phillips Laboratory is developing a solid rocket motor based on state of the art technology, yet adaptable to several of their users' alternatives.

Presently, Phillips Laboratory is operating under constraints that would allow their design to be substituted for the Minuteman III second and third stages. At the same time, the lab's self-imposed limitations are not so binding

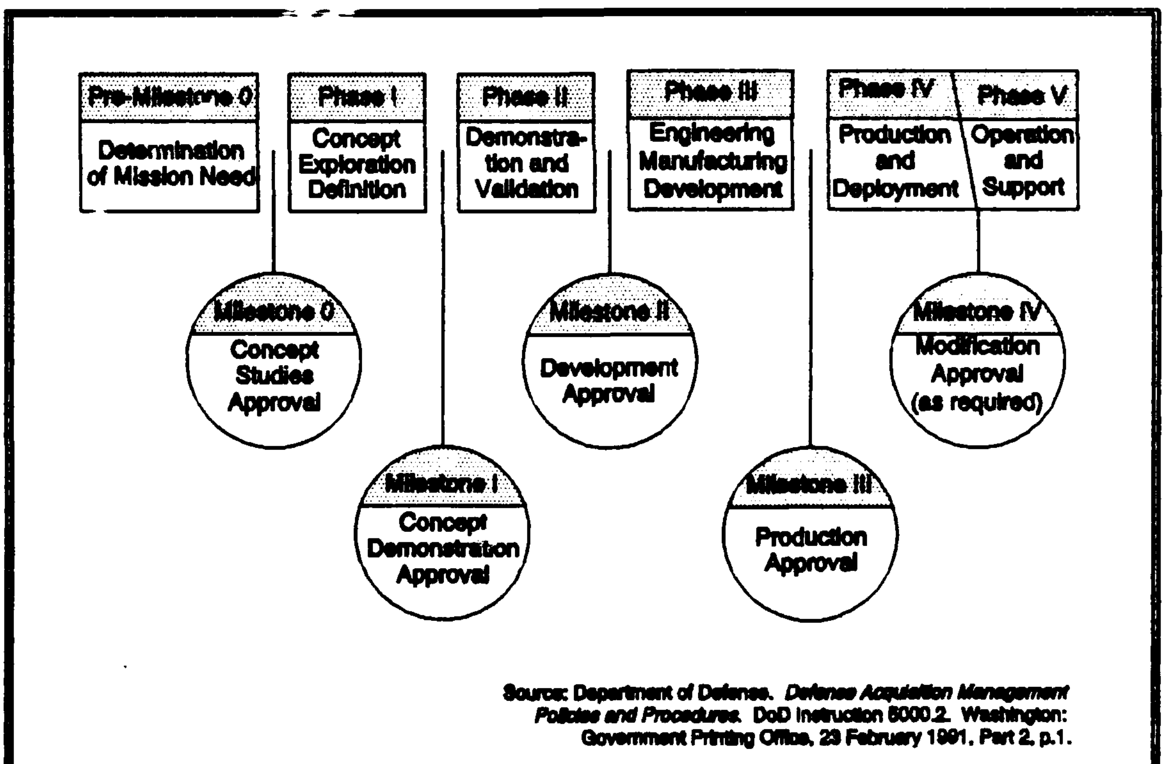


Figure 2-3. DoD Weapon System Acquisition Process

that their product cannot be incorporated into a completely new small ICBM design. Responding to anticipated needs, rather than specific guidance requires this type of flexibility. When the users' requirements (mission needs) are finalized, Phillips Laboratory should have a product that meets their needs. This product will be the complete documentation for a versatile second stage design, to include life-cycle cost estimates.

Life-Cycle Cost Estimates

Life-cycle costs are the "cradle to grave" expenses associated with a given program. These costs include ". . . all expenses for [system] research and development, production, modification, transportation, introduction of the item into the inventory, new facilities, operation, support, maintenance, disposal, and any other costs of ownership, less any salvage revenue at the end of its lifetime" (61:9). For cost analysis purposes, the bulk of these costs are generally grouped into three broader categories: research and development, investment, and operations and support. These categories and the behavior, or incurrence, of their respective costs over time are depicted in Figure 2-4. Once again, it is evident that more than just the initial acquisition outlays must be considered when evaluating program costs. Considering the operations and support costs associated with long service lives of most military weapon systems, and the uncertainty involved with congressional

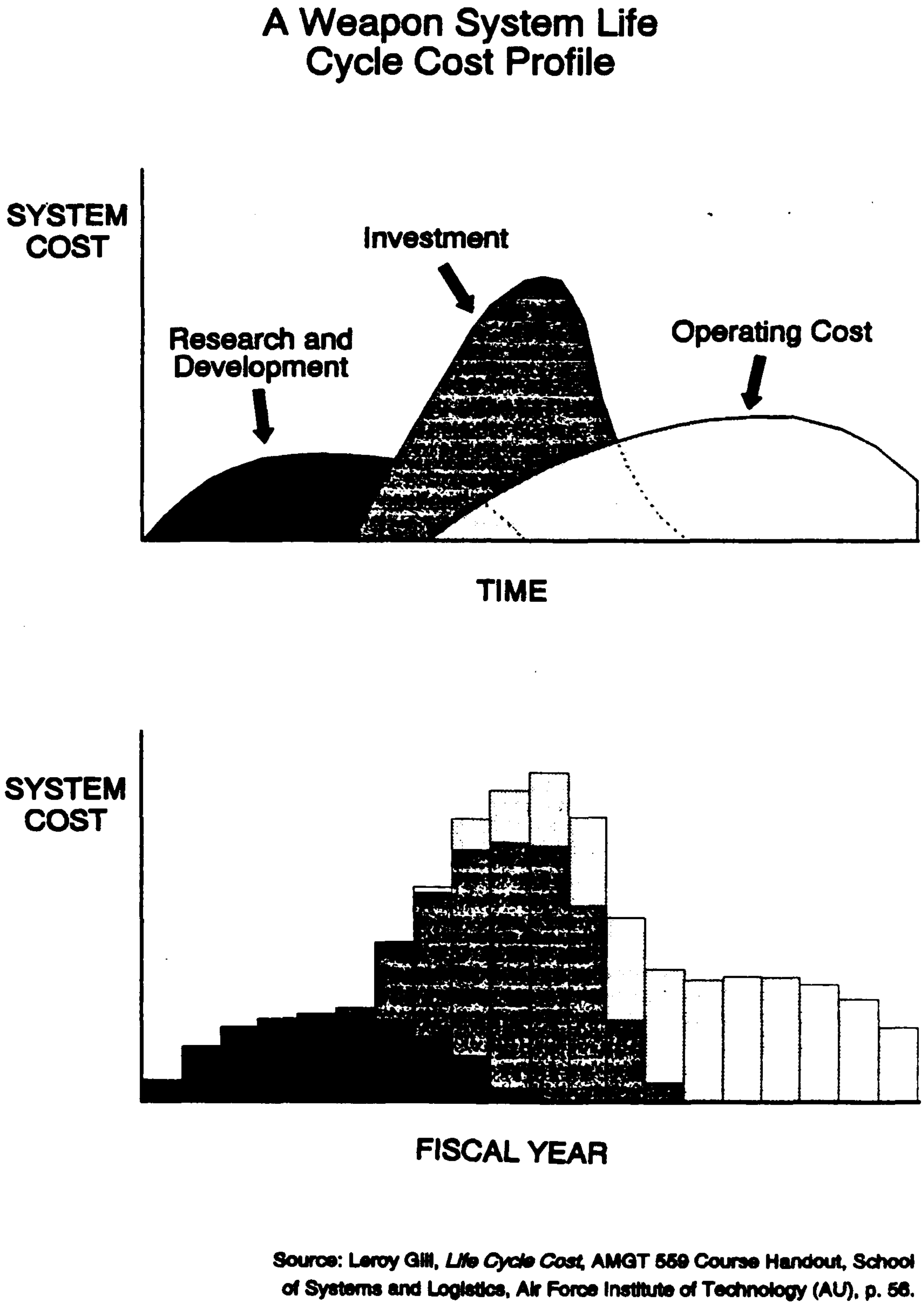


Figure 2-4. Program Life-Cycle Costs over Time

funding of these systems, life-cycle cost estimates are invaluable tools to senior management in the Department of Defense acquisition loop.

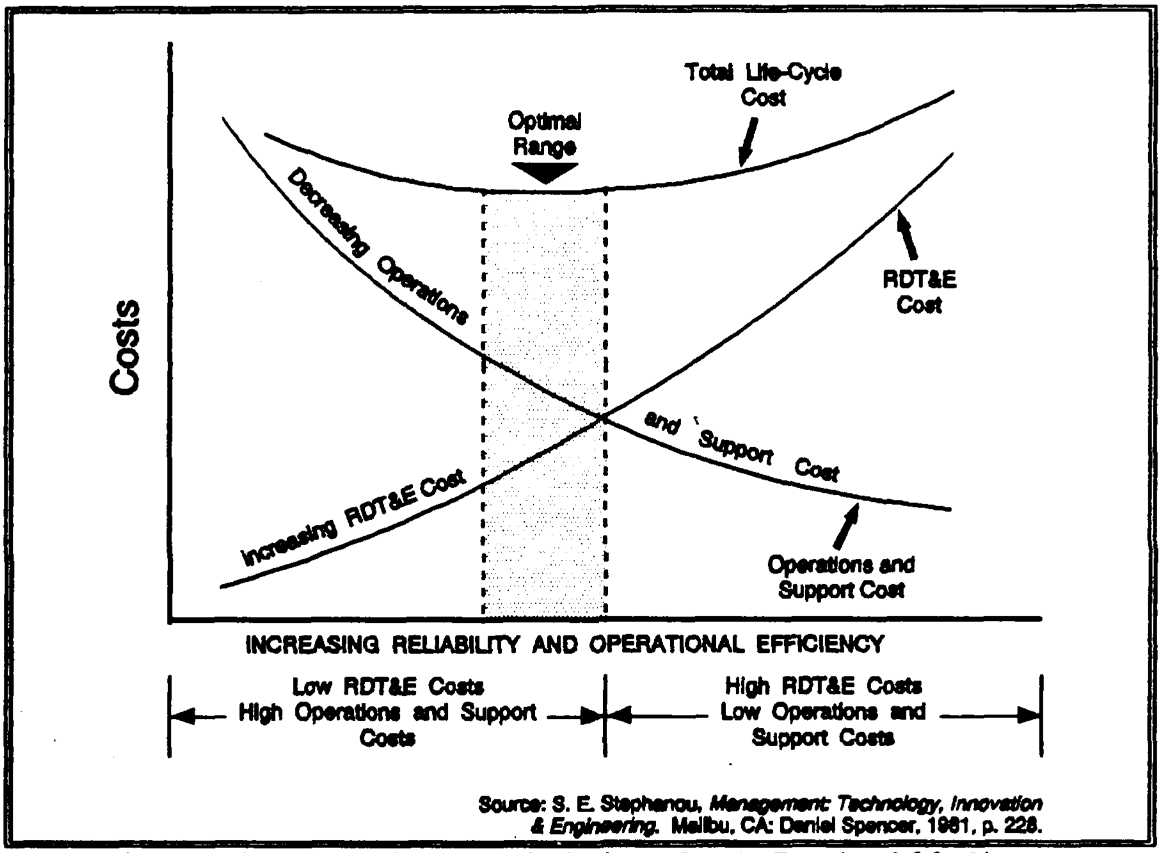


Figure 2-5. Unit Acquisition Cost Trade-Off Chart

In past DoD weapons system acquisitions, "up front" procurement costs were emphasized. Today, the tremendous operations and support costs associated with defense hardware necessitate a total systems view of acquisition costs (61:1-2). Although one system may be more expensive in the initial procurement phase, lower support costs due to improved reliability and maintainability may make this design financially favorable later in the program life-cycle. For this reason, Research, Development, Test and Evaluation (RDT&E), and Operations and Support (O&S) cost-benefit (or "trade-off") analyses are in order during the early stages of conceptual development. The objective of such studies is to identify the optimal range for program expenditures during these two phases of the program life. Figure 2-5 illustrates this point. Present value considerations are particularly important during these "trade-off" studies (see time value of money discussion beginning on page 2-37).

By themselves, life-cycle cost estimates do not identify the optimal solutions. They are certainly a driving force in the defense acquisition process. However, other factors such as the uncertainty of future threats, funding and program life must be considered in this process. With that in mind, life-cycle cost estimates are only useful to the informed decision maker.

In his book, *Life-Cycle Costing: A Better Method of Government Procurement*, Robert Seldon identifies six primary uses for life-cycle costs. These uses are presented below:

1. Long-range planning and budgeting.
2. Comparison of competing programs.
3. Comparison of logistics concepts.
4. Decisions about the replacement of aging equipment.
5. Control over an ongoing program.
6. Selection among competing contractors. (61:11-12)

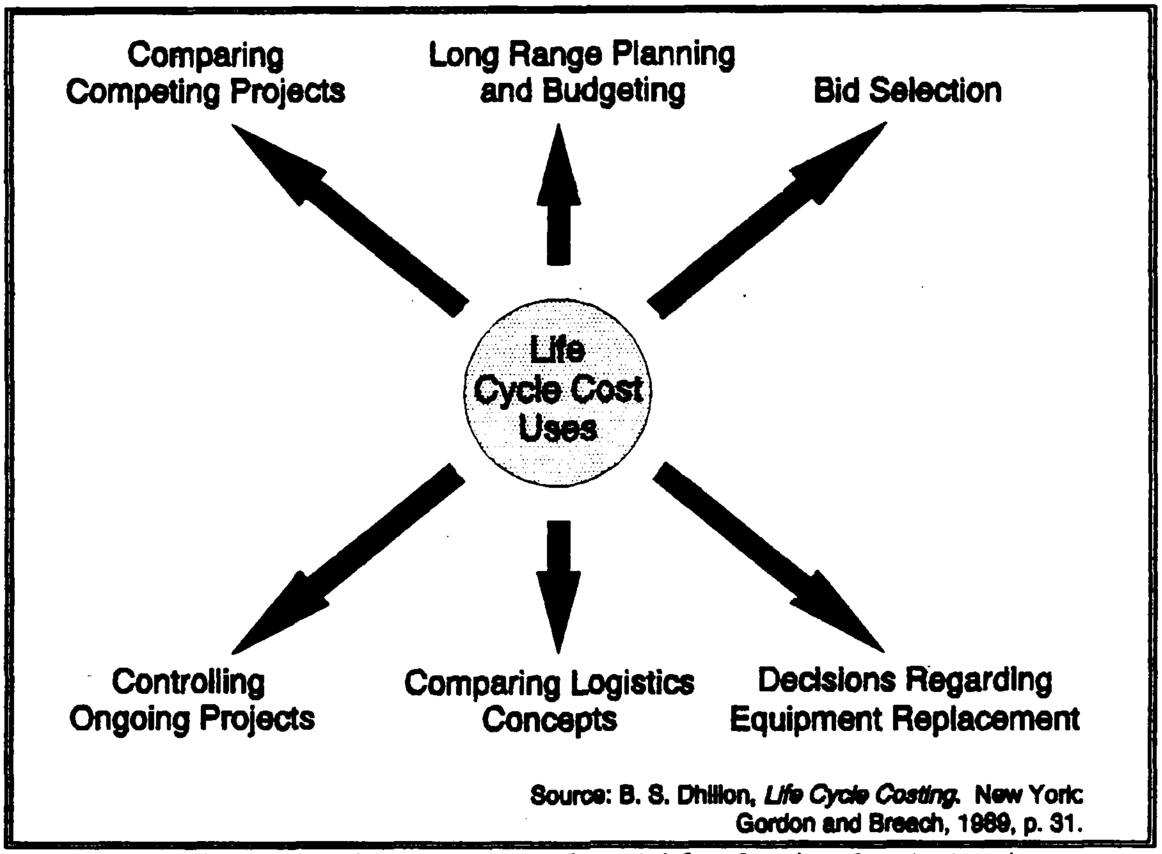


Figure 2-6. Primary Uses for Life-Cycle Cost Analyses

Because of the contract-intense nature of military hardware and services, life-cycle cost estimates serve the last purpose most often in the Department of Defense (61:12).

As evidenced by the organization of Mr. Seldon's book, the system life-cycle may be broken down into process-oriented segments. Specifically, he addresses life-cycle cost estimating for each of the following distinguishable phases of a program life: research and development, production, operations and support, and miscellaneous costs and revenue (e.g., salvage, foreign military sales, and modification programs) (61:ix-x). Dividing programs into manageable levels like this facilitates progress monitoring and reporting, and strengthens the general organization of the program. This "work breakdown" approach also enhances cost estimating efforts.

> Research and development (R&D) costs include all of the expenses necessary to produce a set of engineering drawings and specifications for release to manufacturing; this covers the conceptual, validation, and full-scale development phases. It also includes systems engineering studies, design, development, testing, prototype fabrication and testing, pilot line fabrication, operations and support planning, and manufacturing planning. (61:21)

Production costs include direct and indirect materials and charges, nonrecurring and recurring costs, allocated direct charges, overtime allowances, general and administrative (G&A) costs and profits (61:44-46). Essentially, they are the costs associated with producing the end item. As noted previously, these initial procurement costs were the focus of acquisition decisions until the advent of life-cycle cost analysis (61:1-3).

Operations and support costs are generally the largest component of the life-cycle cost (61:67).

> Operating costs are [those costs] incurred during the use of an item (personnel, fuel, and operating support), and support costs are those [incurred] for maintenance, provisioning, support equipment, training, technical manuals, and other nonoperating

support functions (site preparation and installation and security requirements). (61:67)

Because these expenditures are a major portion of the overall program cost, a great deal of emphasis is now placed on extra spending up front, during the R&D phase. The rationale for this approach is that extra R&D outlays result in higher quality equipment with improved reliability and maintainability. Consequently, this hardware will be more economical to support in the long run.

Miscellaneous costs and revenues are the remaining outlays and inflows over the life of the program that are not readily attributable to one of the three primary life-cycle phases noted. Examples of miscellaneous costs include, construction of support facilities, disposal of by-products, system upgrades and modifications (61:105-106). The revenues associated with a given program include salvage and proceeds from foreign military sales (where applicable).

Cost Estimating

"A cost estimate is a judgement or opinion regarding the cost of an object, commodity, or service" (52:1). Estimates of cost are based on historical data and analogous systems or, when data is not available, personal experience or the expert opinion of others. Cost estimating is a combination of qualitative and quantitative methods for predicting future system expenditures based on available data and sources of related information.

Cost Modeling

"A cost model is a set of mathematical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs (cost estimates) are derived from inputs (descriptions of the equipment, organization, or system)" (52:279). In other words, a model is an equation or set of equations that has a dependent variable (cost) and one or more independent variables (cost drivers). When several equations are involved, each individual equation in the model is referred to as a cost estimating relationship (CER). The CERs generally address a specific aspect or component of the program in question, such as the landing gear on an aircraft.

When developing cost models, the first step is to identify the major factors that are determined to have a significant impact on the cost of the system (44). Examples of factors related to cost include size, performance, and technological advances. After they have been identified, these cost factors must be quantified. A quantified cost factor is referred to as a cost driver. The relationship between cost drivers and major factors is not necessarily one for one (44). A cost driver may be a quantification of more than one cost factor. In the same respect, two or more cost drivers may be necessary to address a given factor.

Once the relationship between the cost drivers and major factors has been established, the analyst statistically analyzes the data to determine the functional (equation) form of each cost driver. This process is usually through the use of regression analysis techniques.

In the cost estimating profession, different methods may be used to estimate costs. The three formal estimating techniques employed are parametric estimating, comparison with analogous systems, and direct engineering and manufacturing estimates. Generally, the current program phase drives which technique is most appropriate. However, all three approaches are used to generate the same end-product: the program life-cycle cost estimate.

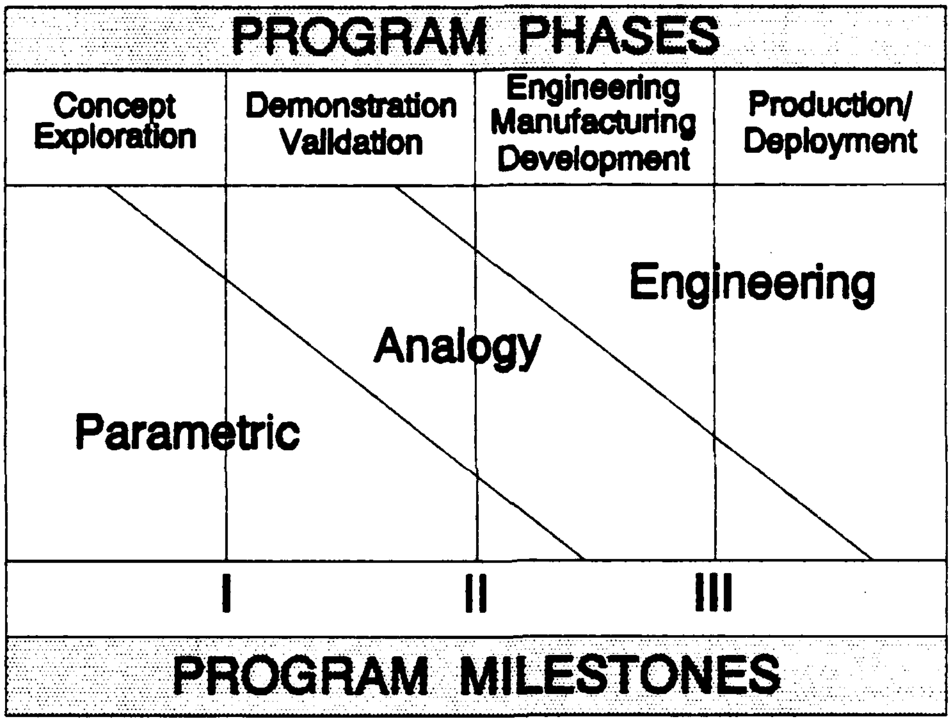
"Estimates by analogy and the parametric methodology are both 'top down' methods, because they examine the program as a whole" (32:7). Direct engineering and manufacturing estimates are bottom-up figures since the overall prediction in this case is based on the aggregate of cost estimates for each individual component (32:7). Regardless of the method selected, the program work breakdown structure (a program management tool) is the central focus of cost estimating efforts. It is the level of detail at which the work breakdown structure is addressed that differentiates between quantitative cost estimating methodologies.

Parametric Estimates. As Stewart and Wyskida note in the *Cost Estimator's Reference Manual*, "Statistical techniques based on population values are called parametric, since population values are 'parameters'" (62:86). *AFSCM 173-1, Cost Estimating Procedures,* relates parametrics to cost estimating by stating, "Parametric cost analysis involves the development and utilization of estimating relationships between historical costs and physical and/or performance characteristics of a system" (23:Sec 5,4). Examples of performance characteristics are speed, range, ceiling, throw weight, and time on target. Examples of physical characteristics include weight, length, and number of engines. In parametric estimating, historical costs are related to these characteristics because costs ". . . reflect the impact of system growth, engineering changes, program stretchouts, and any other cost, schedule, or performance difficulties encountered in comparable programs" (23:Sec 5,4). In other words, a causal relationship exists between selected program characteristics and program costs when parametric methods are properly applied. Regression analysis, or "least square best fit," is a commonly applied parametric estimating approach (see related discussion beginning on page 2-27).

The product of quantitative estimating methods are equations known as cost estimating relationships (CERs). CERs are developed to quantify specific characteristics of a system. In the case of parametric estimating, CERs are used in ". . . an attempt to define mathematically the precise form of a cause-effect relationship in which effect (cost) can be estimates on the basis of cause (weight, performance, quantity, etc.)" (6:Vol 1,13).

Analogy Estimates. "Analogy estimates are conducted by adjusting the known costs of existing systems, similar to the one in question, to arrive at cost projections" (51:15). This method can only be used when data for closely related existing systems are available. Generally, the related systems are compared and intuitively analyzed to arrive at scaling or adjustment factors. "Analogy estimates are usually conducted very early in the development of a future system to try to gauge the approximate order of magnitude of the expected total cost" (32:7). This practice greatly aides the decision making process by illustrating the cost impact a decision is likely to have over a given period of time. "The resulting CERs are acceptable estimators, given there is a good understanding of the relationship between a future system and those on which the analogy is based" (6:Vol 1,13). "Surprisingly, such estimates are usually accurate if the significant changes between programs are understood and accounted for" (61:25).

Engineering and Manufacturing Estimates. "Engineering CERs involve the use of detailed technical information to derive 'bottom-up' estimates" (6:Vol 1,13). Performance of bottom-up estimates requires detailed design knowledge of the specific components and processes for the system. Based on this information, costs for each system component are individually estimated. Finally, the component cost estimates are summed to generate the total system cost prediction. This approach is very time consuming and resource intensive.



Source: John A. Long, *Life Cycle Costing in a Dynamic Environment.* PhD dissertation. Ohio State University, Columbus OH, 1983, p. 40.

Figure 2-7. Quantitative Estimating Hierarchy

The "appropriate" estimating technique to employ in a give situation is phase dependent. Specifically, the current program status with respect to the DoD acquisition process will determine which of the three formal approaches applies.

Parametric methods are generally useful early in the acquisition process, when detailed technical requirements are not yet available. "Typically, parametric techniques are used in conceptual studies or in budgetary and planning estimates" (8:II-23). Analogy is appropriate when system concepts and development have matured enough to determine the degree of similarity and difference between the program in question and comparable programs. Finally, since engineering estimates require detailed requirements and specific program direction, they are most appropriate after the program is approved for production. The quantitative estimating hierarchy described is illustrated in Figure 2-7. For a better understanding of where this hierarchy fits into the DoD acquisition process, the reader should also refer to Figure 2-3.

Although the three quantitative estimating techniques are generally applicable over different program phases, it should be noted that often more than one technique is applied during a given phase. For example, in the early conceptual phase of a weapon system program, parametric methods may be used to address aspects of the program for which an abundance of historical data on similar programs is available. At the same time, analogy methods may be used to address new concepts or technologies for which experience is very limited. To illustrate this example, consider the X-29 Saberbat. Because revolutionary technologies were not incorporated in the powerplant, parametric methods were most likely used to estimate costs for the jet engine and its controls and interfaces. On the other hand, radical technologies were involved with the wing structure (an inverted design fabricated from composite materials). As such, experience limited to recent research and experimentation with composite airfoils probably justified some use of analogy based methods for the airframe cost estimates.

From the previous example, it should be clear that a causal relationship is not always necessary for a predictor (previous experimentation and research experience in this case) to be a good or reasonable basis for cost estimates. Furthermore, this example helps demonstrate that previously established causal relationships do not always hold true. Specifically, for aircraft parametrics, weight has always been widely considered to have a positive relationship with cost; as weight increases, so does cost. However, in the X-29 case, weight can no longer be viewed as a cost predictor in this fashion because weight was actually decreased (through use of composites) to improve aircraft performance and capability. Intuitively, enhanced performance and the revolutionary airfoil technology demands a higher cost estimate, yet the previously held cost-to-weight relationship would have costs estimates decreasing as the aircraft is made lighter. The point to be made here is that no matter what method or combination of methods is applied, sound reasoning is also in order when modeling costs.

When revolutionary technologies are developed, experience with closely related programs or historical data may not be sufficient to develop cost models. In this case, the analyst may be forced to rely on personal or expert opinion to develop program (or component) cost estimates. This is known as qualitative cost estimating, and it is equally as important as quantitative methods in the cost modeling process. Realistically, most cost estimating involves some combination of the two techniques.

Regression Analysis

Quantitative cost modeling is synonymous with causal forecasting. Causal forecasting assumes a cause-effect relationship can be established between the value to be predicted and one or more independent factors, or variables (40:9). An example of cause-effect relationships is miles per gallon (the dependent variable) as a function of automobile weight and engine displacement (the independent variables). Intuitively, the following conditions must exist in order to apply causal forecasting techniques:

1. Historical information must be available
2. This information must be numerically quantifiable
3. Past behavior is assumed to be indicative of future performance (40:8-9)

"The most common quantitative causal forecasting model is regression analysis" (58:96). "'Regression analysis' uses a formal model to measure the *average* amount of change in the dependent variable that is associated with unit changes in the amounts of one or more independent variables" (34, 35:765). If the model considers only one independent variable, the process is referred to as "simple regression." Where two or more independent variables are involved, the analysis is called "multiple regression." Regression analysis is an attractive cost estimating tool because (1) probable error statistics are generated along with the estimates; (2) available procedures allow examination of how well the underlying model assumptions fit the data under review; and (3) it can be applied with several independent variables instead of just one (34, 35:765).

Least Squares, Best Fit. The most common approach to regression analysis is referred to as "ordinary least squares," or "least squares, best fit" (34, 35:346). The "least squares" method produces an equation for a line when simple regression is use, or a response surface (e.g., a plane) under multiple regression (46:227,233). General forms of these equations are expressed as follows (46:31,229):

simple regression: $Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$ (1)

where

Y_i = the value of the i^{th} dependent variable, for 1 through i historical data values

β_0 = a constant (the Y intercept)

β_1 = the independent variable coefficient, or parameter

X_i = i^{th} value for the independent variable (a known constant; the historical data values)

ϵ_i = the random error term

multiple regression:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_{p-1} X_{i,p-1} + \epsilon_i \qquad (2)$$

where

$\beta_2, \ldots, \beta_{p-1}$ = values for additional independent variable coefficients

$X_{i1}, \ldots, X_{i,p-1}$ = i^{th} values for additional independent variables

The distance between a line or response surface and the actual data point being modeled is referred to as the error term, or ϵ_i. Given the independent variable(s) selected to model a cause-effect relationship, the equations above minimize the sum of the squared error terms for each data point (47:478). In other words, they generate the line or surface that best fits, or models, the data; hence, the name "least squares, best fit." Figure 2-8 illustrates this concept for a simple regression case. It should be noted that regression models are not limited to the general forms presented here. Quite often the "best fitting" model is found when independent variables are expressed with exponents or the data is logarithmically transformed before modeling (resulting in a model with log variables), or some combination of the two takes place.

<u>Regression Model Evaluation Criteria</u>. Because a regression model may include a variety of independent

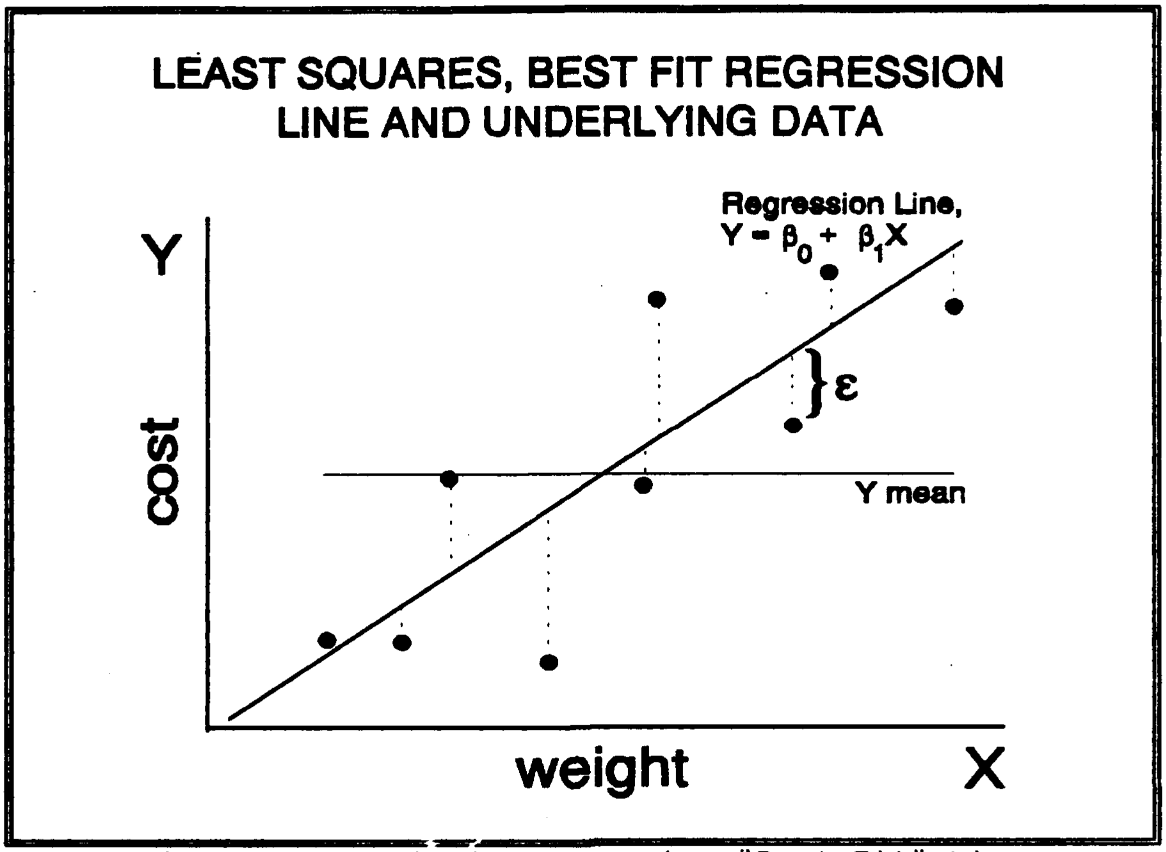


Figure 2-8. Simple Regression "Best Fit" Line

variables in any number of forms (exponents, logs, etc.), some sort of check is in order to select a reasonably useful model. Criteria used in making this selection include economic plausibility assessments, goodness of fit tests, evaluation of the independent variable significance, and specification analysis (34, 35:767).

Economic plausibility assessment is essentially a sanity check. "The regression equation should make economic sense and be intuitive to [the user] . . ." (34, 35:767). For example, if we are predicting the cost of an aircraft, it would not make sense to have a negative coefficient for the independent variable of thrust (meaning cost decreases as thrust increases), even if the variable in this form seems to produce good results. The situation described can easily occur and be overlooked when multiple regression is used.

Goodness of fit is a measure of how well the regression line or response surface fits the data, and it is typically measured through the coefficient of determination, or r^2. The coefficient of determination is the ratio of the sum of squared error terms for the line (or surface) of best fit, to the sum of squared distances between the actual data points and their mean. The calculation for r^2 will always result in a value between 0 and 1. "As an index of fit, [r^2] is interpreted as the total proportion of variance in [the dependent variable] explained by [the independent variable(s)]" (29:607). In other words, it is a technique for determining whether the regression model is a better predictor for the dependent variables than their simple mean (29:607). If r^2 is large, the model is said to have significant explanatory power. If it is small, the mean may be a better basis for estimates.

Significance of the independent variable(s) is measured through the *t-statistic*. The *t-statistic* is the absolute value of a given independent variable's coefficient divided by the variable's standard error (34:767). As a rule of thumb, an independent variable significantly enhances the regression model's explanatory power when the *t-statistic* is at least 2.00 (34:767). For independent variables with *t-statistics* less than this, consideration should be given to removing the variable from the model since it most likely degrades the model's predicting power.

Specification analysis involves a sanity check of the regression model's underlying assumptions. For example, if cost for a new composite fighter is estimated using a model based on historical data for conventional fighters made of aluminum, steel and titanium, aircraft weight as an independent variable in the model wculd probably invalidate the estimate. This is so because the model was originally specified to reflect a positive relationship between weight and cost (i.e., as weight increased, cost increased). However, revolutionary composite technology would rasult in comparatively lighter weight aircraft. Logically, one would expect this technology and the associated performance to cost more; not less. In this case, the fighter aircraft cost model is misspecified for the given objective.

In summary, regression analysis is a powerful cost estimating tool. However, it should not be approached as a simple academic answer to cost modeling. Assessment of the regression model's statistics and its underlying assumptions is a prerequisite to valid cost estimates. Common sense and awareness of considerations external to the model are in order as well.

Learning Curve Influences

Picture the mechanically inclined automobile owner and how much less time and oil were expended during his last oil and filter change compared to his first ever attempt at it. This scenario is a crude, but accurate example of the learning curve phenomenon. As Paul Gallagher notes in his book, *Parametric Estimating for Executives and Estimators*, "A thorough knowledge of learning curves and related techniques can be one of the most important assets of [the cost] estimator . . ." (31:112). Learning curves describe the decreasing per unit costs associated with repetitive mental and/or physical tasks. Essentially, as production workers and supervisors acquire experience at a given task, they learn through trial and error to perform the task more efficiently (33:35). Because of this phenomenon, one can generally expect per unit labor and material expenditures to decrease over time where mass production is involved.

For a better illustration of the learning curve process, consider an aircraft assembly plant for a new line of Air Force fighters. Production of the first prototypes will be very resource intensive as plant engineers, managers, and technicians continually restructure the assembly line to facilitate subassembly integration, adjust and modify tooling for unique characteristics of the aircraft, and establish setup and fabrication procedures for the first time. By the time the first production run starts, hundreds (or thousands) of procedural and technical changes will be made to address lessons learned from the prototype production batch. Additionally, assembly workers will have honed their skills somewhat, making fewer mistakes and better use of their time. Assuming no radical changes to the initial aircraft design, less time and material (in terms of waste) will be required to produce the next aircraft. This learning process will continue with each new production run of this aircraft. However, because manufacturing practices approach perfect efficiency with each new unit, the effects of the learning curve are less pronounced for subsequent units. Not surprisingly, it has been shown that the learning curve phenomenon follows an exponentially decreasing pattern. This fact is evident in the following, universally applied cumulative average learning curve formula (59:Ch 3,3):

$$Y_X = AX^b \tag{3}$$

where

Y_X = cumulative average cost of X units

A = cost of the first unit

X = cumulative units

$$b = \frac{\text{natural logarithm of the learning curve slope}}{\text{natural logarithm of the number 2}}$$

To understand how equation (3) applies ties into learning curves, assume the fighter aircraft above have been produced at a first unit cost of $10,000,000 and the industry accepted learning curve slope for fighter aircraft technology is eighty-five percent. The first lot of twelve (aircraft 1 through 12) should have a cumulative average cost of Y_{12} = $\$10,000,000(12)^{-0.234}$ = $\$5,584,309$ *each*, or $67,011,716 for the entire lot. Since learning curves follow an exponential progression, we can expect the average cost for the first twenty-four units (aircraft 1 through 24) to be eight-five percent that of the first twelve units, or approximately $4,746,662 each. Applying equation (3), the average per unit cost of the first twenty-four units is in fact Y_{24} = $\$10,000,000(24)^{-0.234}$ = $\$4,746,663$. A simpler way of viewing this is that every time total production is doubled (always counting from the first production unit), the new average unit cost decreases to a percentage (the learning curve slope) of the old average unit cost. So in the previous example, the average unit cost for the first forty-eight units of production would be eighty-five percent that of the first twenty-four units, and so on.

The significance of learning curves as they apply to cost modeling cannot be underestimated. Simple projections of large production run costs based on one constant unit cost (as measured for the first few units produced) will result in grossly inflated estimates. A little pencil-work and intuitive thinking reveals that for an eighty percent learning curve task, an identical sized, second production batch must be accomplished at a cost equal to 60.63 percent that of the first batch (31:127)! Consequently, the estimated sizes of total production runs and applicable learning curve slopes

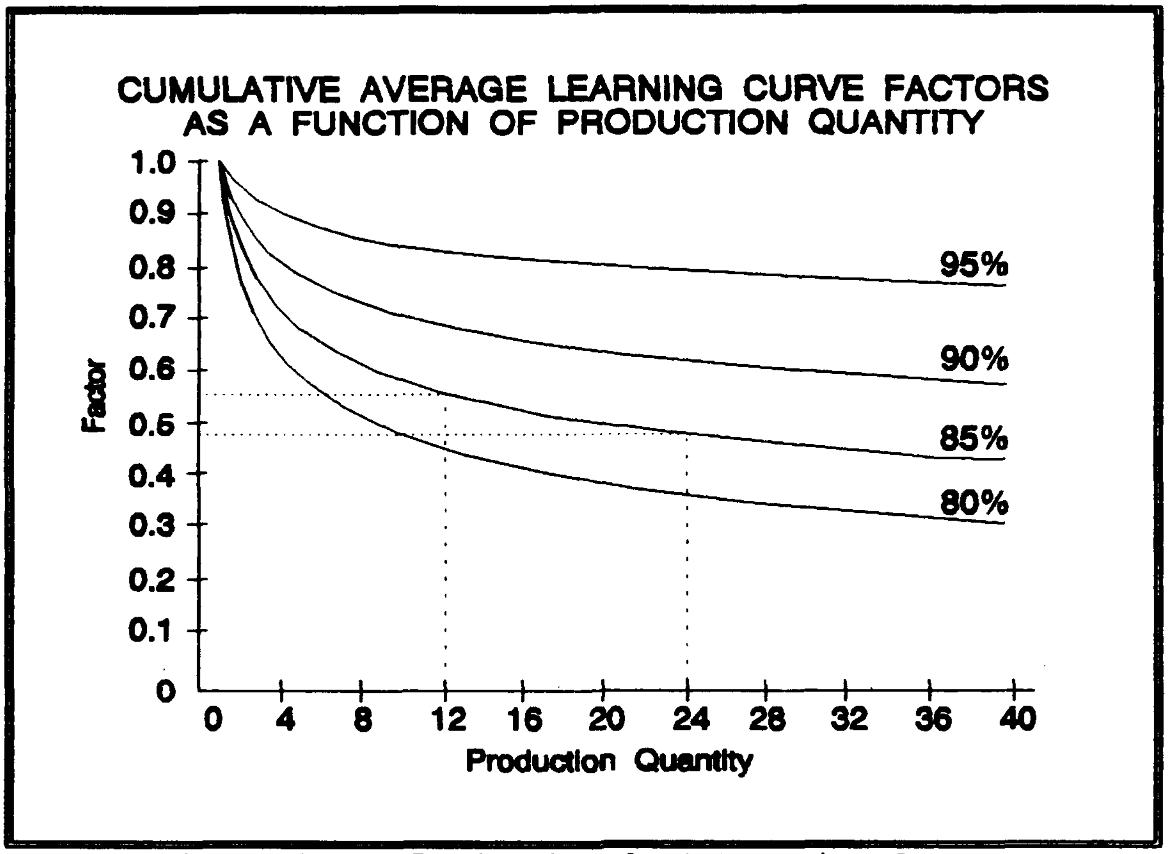


Figure 2-9. Production Cost Learning Curves

play a vital role in the overall life-cycle cost estimate.

The learning curve function is must accurately described through its underlying logarithmic equations described above. However, in practice and throughout cost estimating literature, tables and graphic plots generated from these equations are often presented for ease of understanding and application. A graphic example of common cumulative average learning curve values is depicted in Figure 2-9. Note the ease with which this chart may be applied. The learning curve plot illustrated here reinforces the numeric example previously presented.

Time Value of Money Considerations

"A dollar today is not worth a dollar tomorrow; it is worth more because it could be lent out or placed on deposit, and then be reclaimed with interest when tomorrow arrives" (13:1). Because of this interest premium associated with deferred consumption on the lender's part, effective comparison of competing acquisition alternatives requires present value analyses for each phase of a system's life-cycle. The present value discount rate is the mechanism used to maintain consistency (i.e., constant year dollar figures) among alternatives and preclude "apples and oranges" comparisons. Essentially, the discount rate is the implied "price" of money (33:46). It is the amount of compensation sufficient enough to persuade the lender to postpone his consumption to a later date. For example, a discount rate of five percent means the "price" of borrowing $100 for a year is $5. The actual equations used to derive present value figures follow (13:23,88):

For a single payment,

$$S_0 = \frac{S_n}{(1 + r)^n} \tag{4}$$

where

S_0 = present value of a payment to be made in period n

S_n = actual payment to be made in period n (i.e., future value)

r = interest, or discount rate

n = future period

For a constant flow of equal payments (annuity),

$$S_0 = S_n(pvaf) \tag{5}$$

where

S_0 = present value of the stream of payments through period n

S_n = actual constant payments

pvaf = present value annuity factor for n periods at the desired discount rate, r

To illustrate how these equations are applied, consider a payment of $5,000 to be made (or received) three years from today. Assume the applicable discount, or interest rate is four percent. Applying equation (4), the present value of this payment is $S_0 = \$5000/(1+.04)^3 = \$4,445$. In other words, if $4,445 were placed in a savings account yielding four percent annually, it would be worth $5,000 three years from today. Now consider a series of $2,000 payments to be made (or received) annually for the next three years. Assume the same discount rate of four percent applies. Referring to annuity tables in most any college finance text, the present value annuity factor (pvaf) is found to be 2.775. Using equation (5) above, the present value of the three payments is $S_0 = \$2,000(2.775) = \$5,550$. Note that the pvaf value can also be obtained by summing the *single payment* discount factors for each of the three years (i.e., $1/(1+.04)^1 + 1/(1+.04)^2 + 1/(1+.04)^3 = 2.775$).

The discount rate accepted within the DoD is ten percent. This is the "price" the government has assigned to funds obtained through personnel and corporate tax revenues. Use of this rate allows the military cost analyst to normalize multi-year expenditures and more accurately identify the point or conditions under which one design or strategy becomes financially favorable over the other.

Effects of Inflation

Inflation occurs when the supply of money and credit grows faster than the corresponding supply of consumer goods. The result is a rise in price level which is synonymous with a decline in the purchasing power of each individual dollar. To illustrate, assume the United States has an isolationist policy of no international trade, and the total of annual credit and currency available to its citizens sums to $100. Also assume the annual product of all Americans together is fifty chickens. According to economic equilibrium and the laws of supply and demand, the chickens will be valued at $2 each. Now assume output remains constant at fifty chickens next year, but because of relaxed government fiscal policy or consumer lending policies Americans have a total of $105 in credit and currency available to them that year. The price of chickens will increase, or be inflated to $2.10 each ($105/50 chickens). The point to be made here is that inflation is a function of matching available dollars (or their equivalents) with the supply of goods. *It is not a function of the consumer's preference to spend today rather than defer consumption until a later time*, as is the time value of money concept. These two influences on costs are very independent of each other. Present value analyses adjust figures for the "price" of borrowing money, and nothing more. Consequently, these figures must be "washed" of the effects of inflation *before* present value calculations are applied (33:52). ". . .. the best approach seems to be to first bring all dollars back to a base of standard purchasing power (usually the year in which the decision is being made) and then discount those dollars according to the year in which they will be spent" (33:52). Most good cost models incorporate some sort of inflation table or indices for that purpose.

Application of inflation indices and discount rates together is fairly straight forward. Consider an estimated expenditure of $1,000,000 twelve years from now (2004). Assume this year (1992) is the base year and the projected inflation index for 2002 is 1.20. To "disinflate" this future expenditure, it must first be divided by the inflation index. The result is $833,333 in 1992 dollars. The analysis is not complete until this figure has been discounted at the DoD ten percent rate to arrive at its present value. Applying equation (4), the present value of the planned expenditure, $S_0 = \$833,333/(1+.10)^{12} = \$265,525$. From this example alone, it's easy to see why raw dollar values do not provide an adequate basis for cost analysis. The effects of the time value of money and inflation play a critical role in life-cycle cost studies.

STACEM

Purpose. "The Solid Technology Assessment and Cost Evaluation Model (STACEM) was developed to provide the solid propulsion industry and Government organizations with a reliable tool which can conduct a broad range of life-cycle cost analyses for solid rocket boosters (SRBs)" (6:Vol 1,1). STACEM is a comprehensive cost model that addresses all the potential life-cycle phases for conventional ballistic missile systems. Its purpose is to provide the user with ". . . a tool for quickly evaluating diverse solid propulsion systems, configurations, and life cycle scenarios" (6:Vol 1,1).

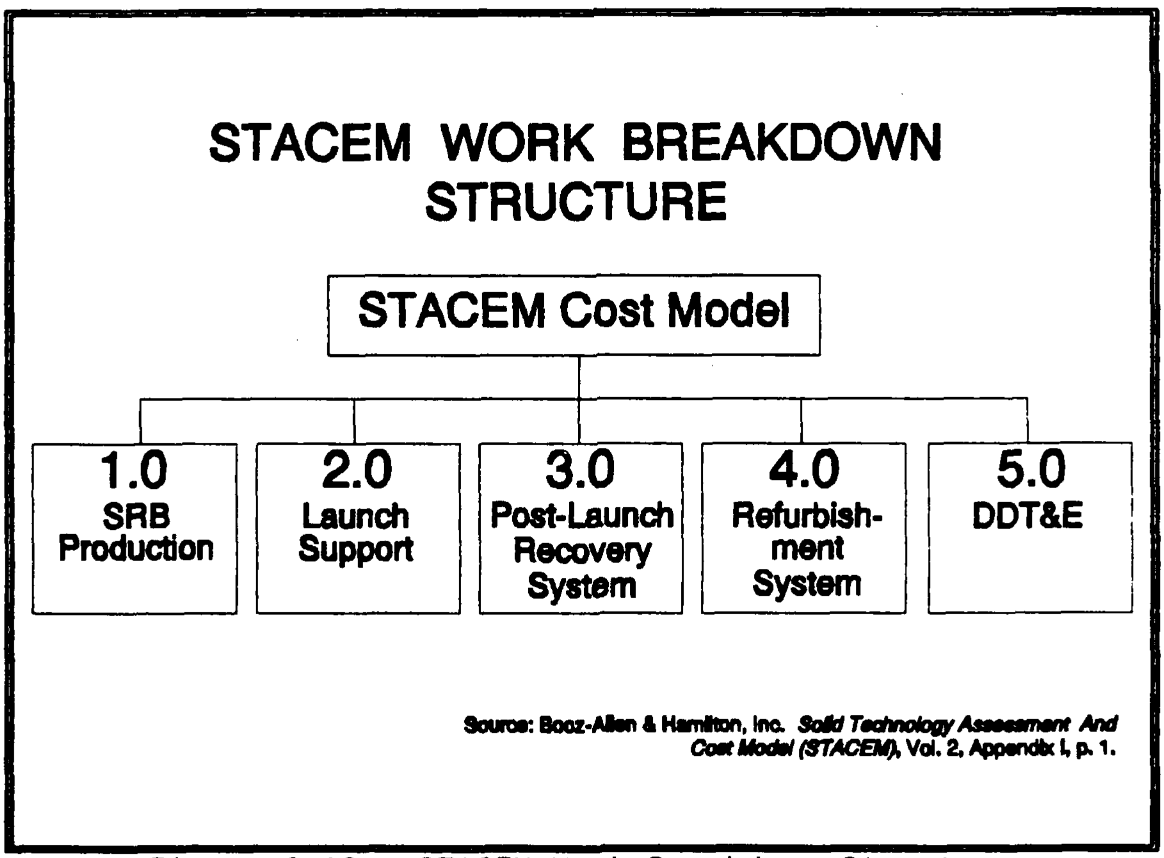
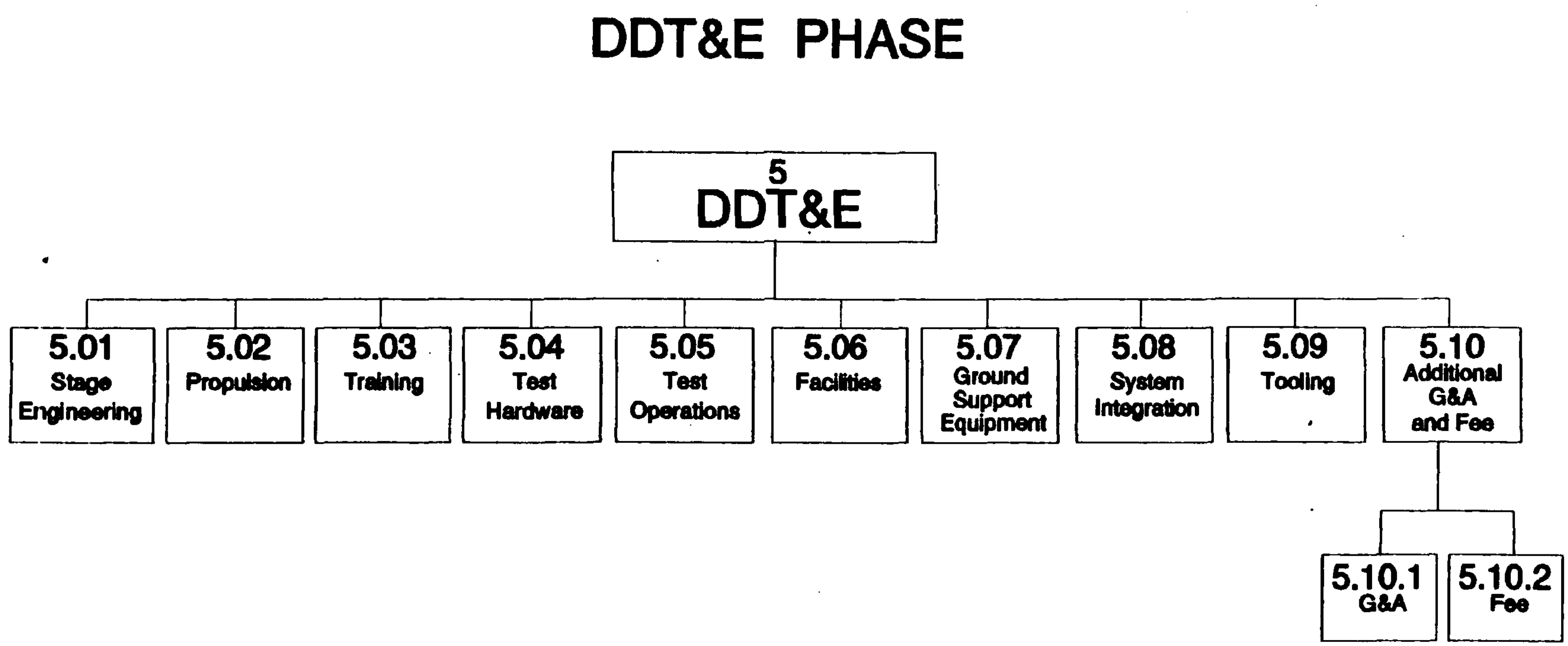


Figure 2-10. STACEM Work Breakdown Structure

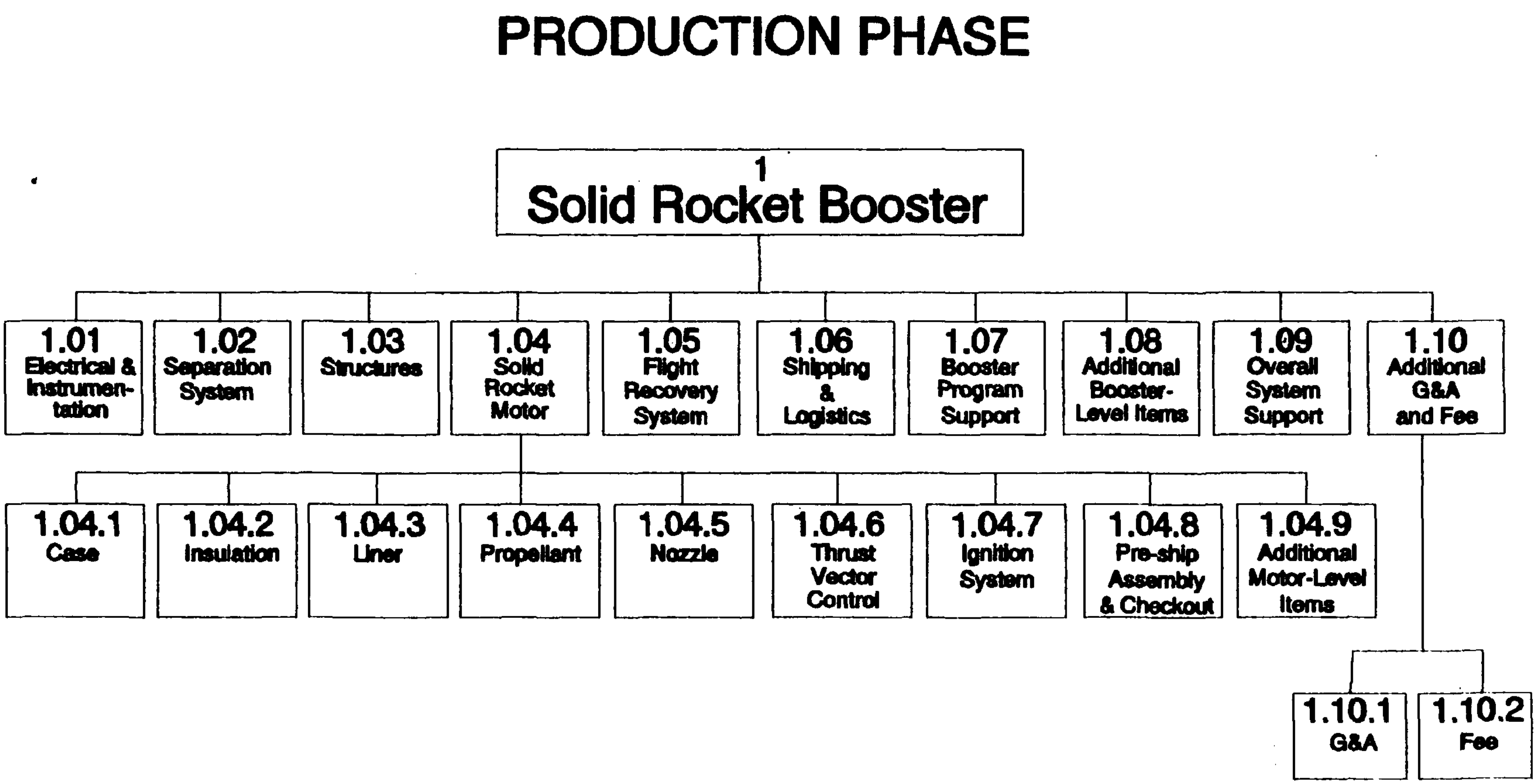
Structure. As noted in Figure 2-10, the model divides the missile life-cycle into five phases, providing a detailed work breakdown structure for each of these phases. The five phases are (1) solid rocket booster production, (2) launch and support, (3) post-launch recovery, (4) refurbishment, and (5) design, development, test and evaluation (DDT&E). Based on these descriptions, the first and fifth phases will probably be the only relevant ones for the Phillips Laboratory ICBM second stage project. STACEM's DDT&E work breakdown structure is presented in Figure 2-11, and the production phase work breakdown structure is illustrated in Figure 2-12. These charts are excellent examples of how cost estimating for sophisticated DoD weapons systems is approached.

Database. As demonstrated in Figures 2-11 and 2-12, the individual program phases in STACEM are broken down further to provide for detailed analysis of the contributing subsystems and processes. The CERs that address each of these components were developed by Booz-Allen & Hamilton, Inc. using two primary sources of cost estimating information. The first source was a comprehensive database of historical cost and technical data collected from various SRB contractors (6:Vol 1,1). A summary of this database and its incorporation into STACEM is presented in Figure 2-13. The second source of estimating data was expert opinion obtained from panels of experienced professionals in the booster industry (6:Vol 1,2). Information from this source was used to develop the



Source: Booz-Allen & Hamilton, Inc. *Solid Technology Assessment And Cost Model (STACEM)*, Vol. 2, Appendix I, p. 19.

Figure 2-11. STACEM DDT&E Phase Work Breakdown Structure



Source: Booz-Allen & Hamilton, Inc. *Solid Technology Assessment And Cost Model (STACEM)*, Vol. 2, Appendix I, p. 2.

Figure 2-12. STACEM Production Phase Work Breakdown Structure

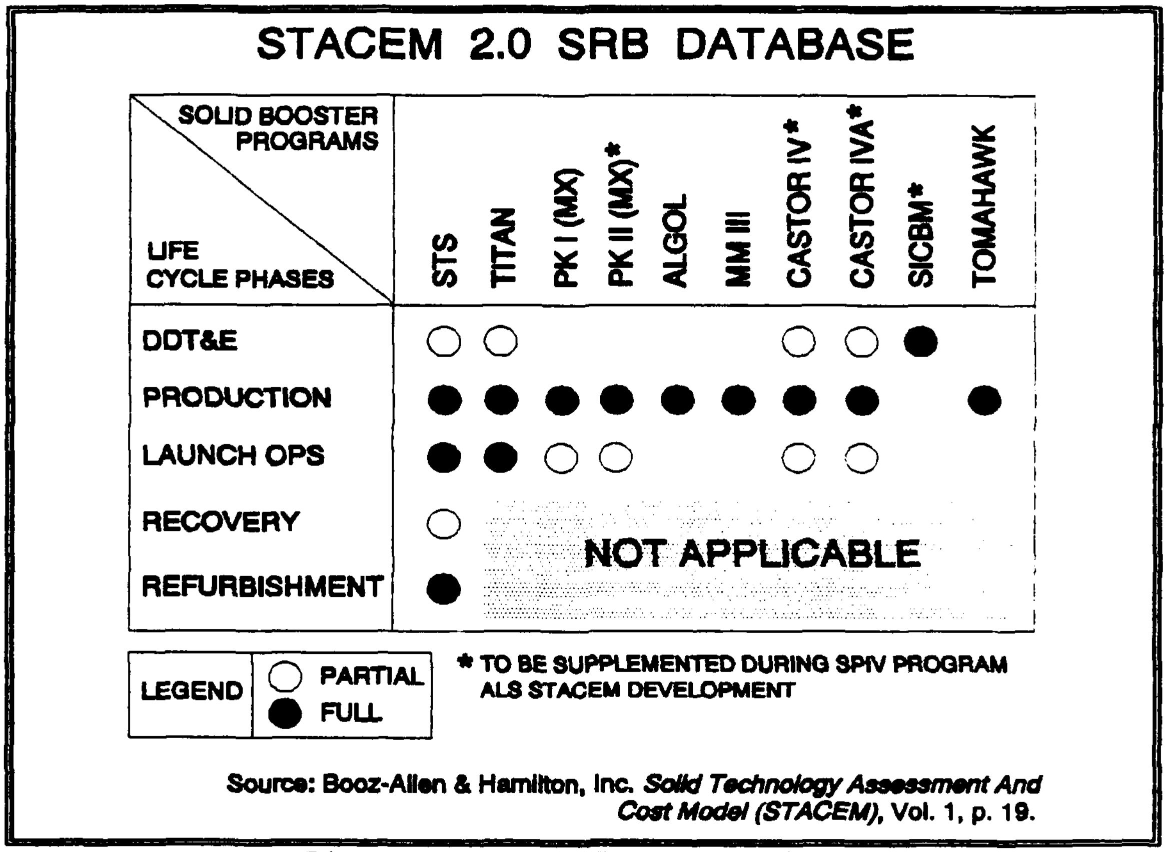


Figure 2-13. STACEM Database

engineering-based "bottoms-up" CERs (6:Vol 1,2). Where neither source provided an adequate basis for CER development, literature reviews were performed to identify existing CERs with potential applications (6:Vol 1,2).

Model Development. "The process used in developing the CERs varied based on the type of cost element and the availability of data" (6:Vol 1,12). Three methods of developing estimates were used in the development of the CERs used in STACEM: analogous cost factors, engineering/piece part cost analysis, and parametrics. Analogous CERs were used for ". . . items whose costs were largely dependent on overall system scale, mission types, and reliability demands associated with manned versus unmanned missions" (6:Vol 1,13). Engineering CERs were developed for recovery, facilities, integration and some support costs for the system. Parametric (regression based) modeling was used primarily for production phase subsystems and processes.

Use of Learning Curves. To compensate for decreasing per unit component production costs, STACEM employs learning curve

Table 2-1.
STACEM Learning Curve Percentages

Case	96%
Propellant	95%
Insulation	100%
Liner	96%
Nozzle	88%
TVC	96%
Ignition	96%
Structures	95%
Electrical and	92%
Recovery	90%

schedules where applicable (6:Vol 1,14). Figure 2-9 depicts an example of the learning curve schedules used in STACEM.

Ballistic missile industry learning curve factors for components of the SRB work breakdown structure are presented in Table 2-1 (6:Vol,14). These are the actual learning curve factors employed by STACEM. As an example of how this table is applied, one can expect the *average unit cost* for the first ten propellant units to be ninety-five percent of the average unit cost for the first five. Furthermore, insulation unit costs should remain fairly constant (i.e., no decrease) regardless of the volume produced. Reference discussion beginning on page 2-33 for a detailed description of learning curves.

Inflation Factors. STACEM also considers the effect of inflation on life-cycle costs via adjustment factors. A plot of the average inflation factors, or indices used by STACEM is presented in Figure 2-14 (6:Vol 1,15). As indicated by the inflation index value of 1.0, the base year for STACEM inflation factors is 1986. A complete, detailed list of indices is available in the software documentation (6:Vol 1,16). For an example as to how inflation factors are applied, refer to the inflation overview that begins on page 2-39.

Model Validation. After STACEM was completely developed, it was validated in two ways. At the summary level, the model was tested through processing of missile data withheld during the model development phase (6:Vol 1,19). At the lower,

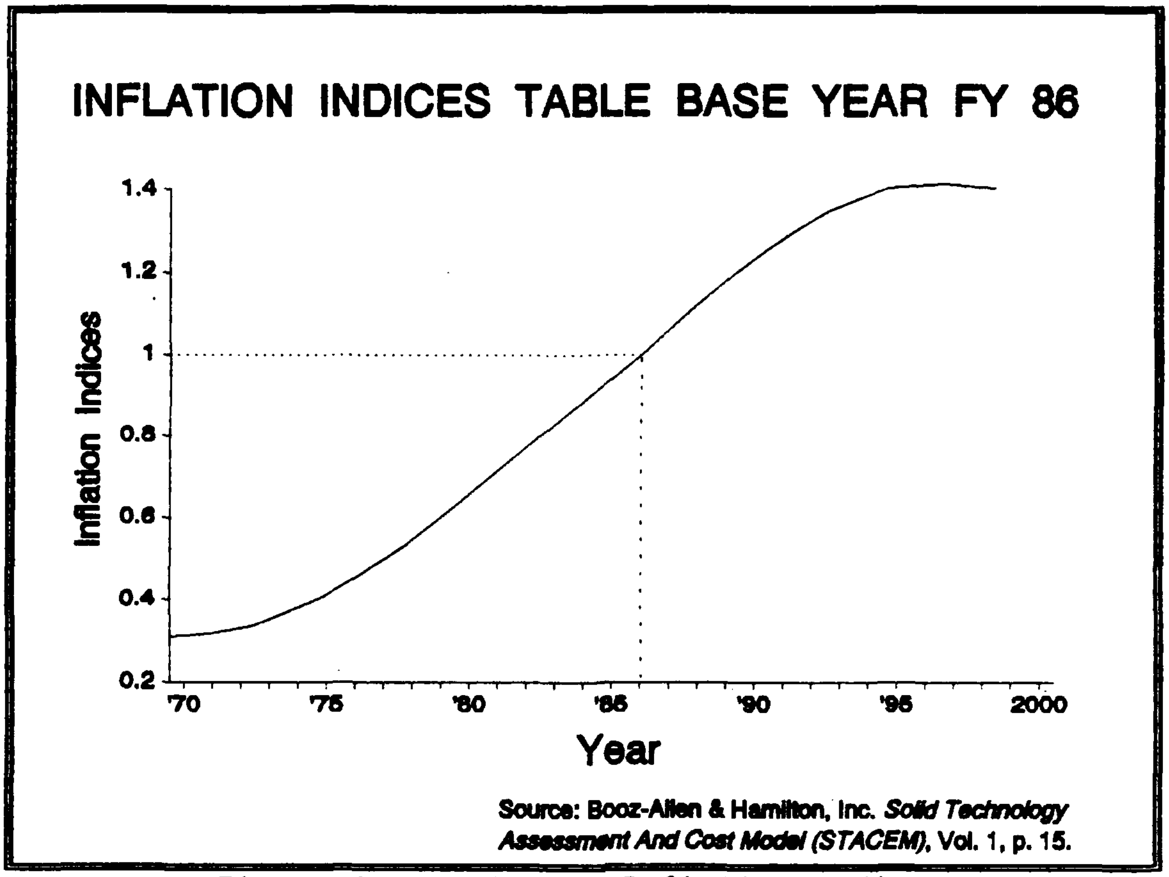


Figure 2-14. STACEM Inflation Indices

detailed level, the logic behind the CERs was examined (i.e., a sanity check) to ensure they ". . . behaved in an acceptable manner given program histories" (6:Vol 1,19). The data used to develop STACEM was gathered under proprietary, non-disclosure agreements to protect the sources' interests. Consequently, the underlying data is not provided with the software. While this approach allows STACEM to reflect industry-wide cost experience without compromising the data integrity of individual companies, it also precludes independent validation of the model's CERs. Only the data sources and generalized validation comments similar to those presented here are included with the STACEM documentation.

Some STACEM validation information is available in the United Technologies *Low Cost Solid Propulsion Study* (10:13). According to this study, STACEM was validated against program cost data for two ballistic missile systems not included in the original cost modeling data base (i.e., "holdout" data). The two systems against which STACEM was validated were the Castor II and the Titan IV solid rocket boosters (10:15-16). These systems were selected to test the effective range of STACEM's CERs (Castor II is a rather small motor, whereas the Titan IV ranks up with the Space Shuttle in size) (10:15-16). Furthermore, detailed cost data on these systems was readily available for comparison with the resulting cost estimates (10:16).

Validation results against the Titan IV, as noted in the study, are summarized in 2-2 (10:15). According to this information, STACEM's prediction for Titan IV life-cycle costs were within 8.7 percent of the actual values. With the Castor II SRB, the authors of the *Low Cost Solid Propulsion Study* used STACEM to develop a unit estimate of $96,843, for an overall 8.3 percent difference from the actual cost of $104,910 as reported under NASA contract NAS7-846 (10:16).

Ideally, measures like those identified under the Regression Model Evaluation Criteria portion of this chapter (refer to discussion beginning on page 2-29) would be presented with software cost model documentation.

Table 2-2.
STACEM Validation with Titan IV Data

PROGRAM PHASE	PREDICTION ACCURACY, %
Overall Program	8.7
Solid Rocket Booster	9.7
Launch Support	8.6
Recovery	N/A
Refurbishment	N/A
DDT&E	4.0

Unfortunately, that was not the case with STACEM. Moreover, the proprietary nature of STACEM's underlying data precluded Booz-Allen and Hamilton from including this information for the user to derive their on model diagnostics. As such, it is not possible to further assess the reasonableness of their model development endeavors. From the validation efforts above, it appears STACEM performs quite well. However, one should bear in mind that even though the programs used to achieve these results were not included in STACEM's database, they were predecessor or successor versions of systems whose costs had been used in the model's development (see Figure 2-13). Since the booster for which we are estimating cost is also a successor program to one included in STACEM's database (Minuteman III), this may not be a significant consideration. Had we been estimating cost for a completely new system, these validation results would not have carried much weight. In either case, actual statistical metrics for the model and its underlying data would have made these validation efforts more convincing.

Chapter Summary

This chapter described the Air Force's current ICBM workhorse, Minuteman III, and addressed new ballistic missile user requirements presented to Phillips Laboratory. It also described life-cycle costs and the components that make up these costs. Cost estimating was defined and the general approaches to cost modeling were discussed. The effects of uncontrollable influences on estimates (i.e., learning curves, time value of money, and inflation) were also identified. Finally, the chapter concluded with information regarding development and validation of the STACEM life-cycle cost model.

Chapter III
Methodology

Chapter Overview

This chapter outlines the work performed to answer the investigative questions listed in Chapter I. Specifically, this section briefly describes how information and data were obtained, analyzed and used to develop second stage booster life-cycle cost estimates.

Work Performed

1. We reviewed technical ballistic missile and life-cycle cost literature available through the AFIT library, DTIC and the Aerospace Systems Division (ASD) Cost Library. From this review, we determined the following:

a. Typical program phases for an expendable ballistic missile booster life-cycle are DDT&E, production, and launch support/operations and support (10:7).

b. Major factors that traditionally affect total expendable booster program cost (in decreasing order of impact) include characteristics of the booster case, the thrust vector control system, the nozzle, the propellent, and the insulation (10:6).

c. Several cost drivers are generally used to address these major factors. Those identified in the *Low Cost Solid Propulsion Study* are listed below (10:6):

Factor	Cost Drivers
Booster Case	Method of manufacture Transportation MEOP or PV/W
Thrust Vector Control	Nozzle design Horsepower (moveable nozzle) Total side impulse (fixed nozzle)
Nozzle	Submergence External loads or heating Manufacturability
Propellent	Specific Impulse Burn Rate Required Reproducibility Processing Method
Insulation	Thickness requirement Method of fabrication Method of Assembly

This information answered our first two investigative questions in Chapter I.

2. We interviewed the AFIT engineers and Phillips Laboratory personnel to determine if the cost drivers noted during our literature review were relevant to their designs, and to identify new technologies used in their designs. Through discussions with Phillips Laboratory personnel, we determined the cost drivers noted above were relevant to both designs (57). From the literature review and other qualitative assessment (i.e., phone survey with Ballistic Missile Organization cost experts), we determined no new technologies were incorporated in either design (57;54;17). The concepts

used in both designs are not revolutionary; they are extensions of existing technologies. As such, complexity factors would adequately capture the effects of the technologies employed. No additional cost drivers are necessary to capture the effects of technology on cost. These findings answered the third set of investigative questions.

3. In Chapter IV, we reviewed STACEM related documentation and determined that desired cost drivers were addressed by this model. Additionally, in that chapter we evaluated STACEM for applicability to the major life-cycle phases of the Phillips Laboratory and AFIT engineering booster designs. We determine STACEM could be applied to the DDT&E and production phases. Under these phases, adjustments to STACEM for technology concerns were made only through complexity factor inputs. These steps addressed investigative question #4.

4. In the operations and support phase, where STACEM did not completely support our cost estimating efforts, we performed the following steps:

a. Obtained booster cost estimating data sources from Phillips Laboratory, the Ballistic Missile Organization and the ASD Cost Library. Available cost data for any United States ballistic missile systems was open to consideration.

(1) We were unable to identify solid rocket motor ballistic missile systems for which cost estimating data was readily available.

(2) Because of the proprietary nature of most ballistic missile cost data, we could not gather information from which to evaluate hypothesized cost drivers. Since availability of missile cost data was limited, judgmental sampling techniques were used to gather the data we were able to obtain.

(3) The data that was gathered was analyzed for completeness and consistency (standardization of units and measures).

b. Working with the Ballistic Missile Organization and Ogden ALC cost experts, we determined the data obtained would support analogous system estimating techniques for the operations and support costs.

c. Using the information gathered above, we applied cost estimating principals and input from Ballistic Missile Organization and Ogden ALC cost experts to develop a second stage booster, operations and support phase cost estimating approach.

These procedures addressed the fifth group of investigative questions.

5. Our final procedures included collection and quantification of final booster design specifications and assumptions. Chapter IV addresses these efforts. We incorporated the values obtained in the selected cost models to develop the life-cycle cost estimates presented in Chapter

V. This step answered the sixth, and final, investigative question.

Chapter Summary

This chapter outlined the work we performed to answer the investigative questions listed in Chapter I. Specifically, this section described how information and data were obtained, analyzed and used to develop second stage booster life-cycle cost estimates.

Chapter IV
Research Findings

Chapter Overview

This chapter identifies the cost models chosen to estimate design, development, test and evaluation (DDT&E), production, and operations and support costs for the proposed booster designs. It addresses the assumptions associated with this program, our rationale for cost model selection, model adjustments we made, and user determined input values for the models. Discussion related to the DDT&E and production portions of our efforts is presented first, followed by operations and support cost documentation, beginning on page 4-11.

DDT&E and Production Costs

Assumptions

Design Considerations. At the time of our review, Phillips Laboratory was advocating a conical shaped booster for their design. The AFIT engineering group was leaning toward a conventional cylindrical shaped design. It is assumed that the STACEM complexity values assigned to the respective designs will adequately capture these differences in design approaches.

It is also assumed that an upgraded missile guidance system (the Advanced Inertial Measurement System, AIMS) will be incorporated in the missiles at the same time booster modification is accomplished (57). Since AFIT and Phillips Laboratory are not involved in that area of research, related DDT&E and production costs are not included in our estimates.

Schedule. Design, development, test & evaluation (DDT&E) is assumed to begin at the start of FY 1994 and span a period of six full years (57). Full scale booster production is assumed to begin at the start of FY 2000 (57).

Production Rate. Once full scale production is initiated, the monthly output rate is assumed to be five boosters per month, for a total of sixty per year (57). The total number of boosters produced will be 674 (500 for operational use, 110 for flight test, twelve for aging and surveillance, twenty-one for ground tests, and thirty-one for production quality assets) (19).

Ground and Flight Test Activity Level. Throughout the DDT&E and production phases, twenty-one boosters will be consumed in ground testing, thirty will be expended in development flight tests, and thirty-one will be destroyed in production testing (18;56). Costs related to these tests will be captured in the DDT&E and production portions of our estimate.

Cost Model Selection. Based on the model validation results discussed in Chapter II, the unavailability of historical booster cost data, and the STACEM cost model review presented in the *Low Cost Solid Propulsion Study*, we elected to use STACEM as our DDT&E and production phase cost estimating model (10). Considering the proprietary nature of the underlying data, the STACEM validation results are reasonable. Furthermore, we were unable to identify any alternative parametric models for these phases of the booster life-cycle.

STACEM Input Variables

Background. Appendix C is a STACEM product that lists the independent variables required to generate a life-cycle cost report using the model. Included in this appendix are the independent variable values provided by Phillips Laboratory and the AFIT engineering group for their respective designs. STACEM was used only for the DDT&E and production phases of the life-cycle; variable inputs that related to launch, recovery, and refurbishment were not required. The DDT&E and production section of Chapter V contains the actual life-cycle cost estimates generated by STACEM for the two designs, based on those inputs in Appendix C.

A list of the cost estimating relationships (CERs) used to estimate the item costs is provided in Appendix B. Appendix A (also a STACEM product) contains detailed descriptions of the variables used in each CER. The following section describes how STACEM generates estimates.

The first twenty-four inputs variables (APX11 through APX5) are complexity factors. They are used to adjust the various categories of cost based on the "technical complexity of the program being analyzed" (7:App B,2). "Technical complexity includes materials, processing, and labor [considerations]" (6:Vol 2,App V,107). Other inputs include weight data for the individual components of the SRB; performance factors like average thrust and total impulse; learning curve factors for the production phase; and estimated cost data for DDT&E and production facilities.

Values for the STACEM input variables were obtained from a variety of sources. Both Phillips Laboratory personnel in California and the AFIT engineers provided the solid rocket booster (SRB) specific inputs. Cost data, for variables such as DDT&E facilities, General and Administrative charges, and Fees, were obtained from Ballistic Missile Organization cost analysts (17;54). The figures obtained were estimates based on historical data from similar missile systems. The cost figures provided were in FY 1991 dollars. Since STACEM requires all input cost data be in FY 1987 constant dollars, we converted the figures into 1987 dollars. This was accomplish through the use of AFR 173-13 based "Inflation Tutorial" software obtained from the Air Force Cost Analysis Agency.

Complexity Factors. Both engineering groups provided the necessary inputs for the complexity factors. This values assigned were based on surveys results of contractor experiences in developing solid rocket motor design technologies. Specifically, the complexity factor value criteria, as defined in STACEM, follows: "For a follow-on program use a complexity factor between .4 and .6; if the technology used is from a related program use a complexity factor between .7 and .9; and for an entirely new program use a complexity factor of 1" (7:App 1,2). Since these values are subjective, differences in opinions can result in significantly different life-cycle cost estimates. Understandably, neither engineering group felt comfortable approximating these factors to two significant digits. As such, we redefined the complexity factor criteria as follows: .6 corresponds to follow-on programs, .9 equates to related programs, and a value of 1 represents an entirely new programs.

Component Weights. Both engineering groups provided the weight variable values for their respective booster designs. Specifically, weight values for the following items were provided by each group as required by STACEM:

Electrical and Instrumentation
Separation Systems
Structures
Flight Recovery
Ignition
Liner
Nozzle

Propellant
Thrust vector control/Thrust Vector Actuator (TVC)/(TVA)
Insulation
Case
Booster recovery (inert)

Some of the weight inputs were assumed constant between the two designs since both incorporate some existing Minuteman III components. In these cases, actual Minuteman III data was used. Specific booster components that were constant between alternatives were the electrical & instrumentation, separation systems, and structures weights. Since ICBMs are expendable, a value of 0 was assigned to the flight recovery and booster recovery variables (56). Thrust vector control weight for each design was determined by summing the individual weights of the four hot-gas injection valves to be used. The remaining components were design dependent, and were determined through trade-off analysis and optimization techniques.

<u>Production Requirements</u>. Production commences in the seventh year. The assumed production rate is five SRB's per month, or sixty boosters per year. A total of 674 booster will be produced based on the following requirements.

Launches in support of flight testing begin in the forth year of DDT&E. Ten flight tests per year are assumed to be conducted during the last three years of DDT&E (17). After DDT&E is complete, the launch rate will be reduced to 4 per year for the operational life of the system (20 years) (56).

Costs associated with these flights are addressed under the operations and support cost portion of our estimate.

Typically, twelve motors are removed from the production line to be stored in hangers that simulate the environment the missile will normally experience. After five years, one motor is dissected to evaluate material integrity (19). The primary concern is with propellant crystallization or separation from the liner. This process is repeated at the ten year point, and once every year after that (19). For STACEM, we assumed twelve motors would be reserved for age testing as well.

Production quality assets (PQA) are motors that are removed from the production line and dissected to evaluate product quality. In practice, the process is performed on every twentieth motor. For STACEM, a value of 31 PQA motors was computed by dividing the total number of motors produced for operational use, flight test, and aging by twenty (19).

Under standard program procedures, one out of every thirty motors produced is reserved for ground testing (18). The number of motors required for ground testing is computed by dividing the sum of all motors needed for operations, flight tests, and age testing, by a factor of thirty.

Launch Complexity. The STACEM launch complexity index is a subjective factor determined by comparing the current system with existing systems. The scale ranges from 1 to 100 with example ratings of 95 for the space shuttle, 60 for the Peacekeeper, and 20 for ALGOL (6:Vol 2,App II,9).

Minuteman III launches are not as complex as the Peacekeeper, so the value of this variable should be less than 60. A value of fifty was assigned to this variable based on discussions with STACEM development personnel at Booz-Allen & Hamilton (4).

Reusable/Expendable Booster. The reusable/expendable booster input is an indicator variable and is used to distinguish between reusable and expendable systems. A value of 1 signifies an expendable system. Reusable systems are assigned a value of 2 (6:Vol 2,App III,5). Both designs are expendable; therefore, a value of 1 was assigned for this variable.

TVC/TVA. The Thrust Vector Control (TVC)/Thrust Vector Actuator (TVA) input is an indicator variable that distinguishes between thrust vectoring options. A value of zero identifies no thrust vectoring, 1 characterizes TVC, and 2 relates to TVA (6:Vol 2,App III,9). Both designs use TVC; therefore, a value of 1 was assigned to this variable.

Moveable/Fixed Nozzle. The moveable/fixed input is another indicator variable which distinguishes between moveable and fixed nozzles. A value of 1 corresponds to fixed nozzles, and a value of 2 means the nozzles are gimballed (moveable). (6:Vol 2,App III,9). Since both designs incorporate fixed nozzles, a value of 1 was assigned to this variable.

Cost of Operations Facilities. The variable addresses ". . . cost estimates for the launch support operation facilities" (6:Vol 2,App III,6). These costs include maintenance, the cost of the command and control facilities and related manpower (4). Since this area is addressed in the operation and support portion of our estimate, no value was assigned to this STACEM variable.

Geographical Distance. It is assumed either Morton Thiokol or Hercules (both SRB producers located near Ogden ALC, Utah) would produce the booster and R&D test facilities at Arnold AFB, Tennessee will be used for ground testing. The distance between Brigham City, Utah (location for Thiokol) and Arnold AFB was determined through the use of AFR 177-135 "Official Table of Distance".

Launch Support Facilities. This variable addresses the cost to build facilities necessary to assemble the SRB's at the flight test facility (4). A value of zero was assigned to this variable because it is assumed that existing Minuteman III facilities will be used.

DDT&E & Production Facilities. Tnis variable is intended to capture the cost of the tooling and production line setup (4). According to the Ballistic Missile Organization, the only setup cost associated with production of an individual solid rocket motor is the cost of tooling. A value of $40,000,000 was assigned to this variable based on comparison of analogous systems (19). This value was expressed in FY 1991 dollars and required conversion to 1992 dollars before it was used. The AFR 173-13 based "Inflation Tutorial" software was used to make this conversion.

Learning Curve Factor. This variable ". . . contains the cumulative average learning curve factors for each phase of the SRB life" (6:Vol 2, App III,7). Since learning curves apply the production phase, no values were assigned to this variable under DDT&E.

In the production phase, different learning rates may apply to individual components of a solid rocket booster. STACEM allows only one input (a composite learning rate) for this variable. The learning curve rate used was 95 percent (19). This value was based on comparison with analogous systems.

Cost of Capitalization. The cost of capitalization is the ". . . minimum acceptable rate of return on an investment, also called the discount rate" (35:948). STACEM requires a value for this required rate of return. A value of ten percent was assigned to this variable because "The required rate of return, or the cost of capital used by the government is 10 percent" (35:721).

<u>General and Administrative Charges</u>. General and administrative charges are assumed to include Sustaining Engineering and Program Management (SEPM) (18). The general and administration charges for the production phase account for approximately ten percent of these costs (18). For DDT&E the percentage increases to twenty percent because more engineering support is required during this phase of the life-cycle (18).

<u>Fees</u>. Fees generally vary from one contractor to next, but they are usually constant between phases of a given program life-cycle (4). We assumed a constant rate between phases as well. Based on discussions with Ballistic Missile Organization personnel, we arrived at a rate of thirteen percent for fees associated with the DDT&E and Production phases (18).

<u>Operations and Support Costs</u>

<u>Assumptions</u>. The following assumptions were coordinated with Phillips Laboratory and AFIT engineers as well as Ballistic Missile Organization cost analysis personnel. Specific sources are noted. *These conditions hold constant fcr both booster designs under review.* This early in the design development phase it should be noted that differences

in the proposed booster designs are not significant enough to merit separate O&S estimating assumptions, conditions and constraints. As such, one O&S cost estimate was developed to address both designs.

Design Considerations. As noted previously, both Phillips Laboratory and the AFIT engineers are operating under the assumption that their second stage booster design will replace the Minuteman III second and third stages without any required structural changes to the remaining missile components (first stage, post-boost vehicle and payload) (57). In other words, the new booster will be a perfect fit. However, both groups have agreed that an upgrade to the aging NS-20 guidance system would most likely accompany any Minuteman life-extension program. In fact, independent research is already underway for a replacement system, the Advanced Inertial Measurement System (AIMS) guidance package (57). It is assumed that this guidance system will be fitted to the modified missiles during the new booster phase-in period. However, because the guidance system design is not addressed through the Phillips Laboratory or AFIT engineers' research, associated DDT&E and production costs are not addressed in our estimate. Furthermore, estimated changes in O&S costs attributable to this change in guidance systems will be highlighted accordingly.

Deployment Schedule. Booster design, development, test and evaluation (DDT&E) is assumed to begin in 1994 (57). Allowing for a six year design phase, full production will begin in the year 2000 (57). At that time, the production rate will be five units per month for a total of sixty boosters per year (57). Of these sixty boosters, three will be destroyed each year through production testing and another four per year will be expended in follow-on test and evaluation (FOT&E) launches (57;17). Additionally, in the first year, twelve boosters will be set aside for age testing (17). As such, a total of forty-one boosters will be available for operational deployment in the first year, and fifty-three units will be available each year after that.

Between the Minuteman III and the modified boosters, it is assumed a constant force of 500 active ICBMs will be maintained during the phase-in period. In the first year of program phase-in, half the boosters available for operations (twenty) are assumed to be deployed and activated. For each year thereafter, fifty-three units will be substituted for Minuteman III second and third stages until the full force of 500 missiles is completely refitted. At this rate, deployment of the new boosters will be complete in the year 2010. For this year and the remaining years of the program, O&S costs are assumed to remain fairly constant (steady state). During the ten years prior (2000 to 2009), operating and support costs associated with the new booster designs will increase annually, in proportion with the number of upgraded missiles deployed. This increasing, then stabilized expenditure pattern will be reflected in our estimate.

Missile Basing. The modified ICBMs will be deployed in the same quantities and utilize the same facilities (silos) as the Minuteman III missiles they will be replacing (57). Specifically, fifty of the new missiles will be based at Malstrom AFB, Montana; 150 will be maintained at Minot AFB, North Dakota; 150 will be stationed at Grand Forks AFB, North Dakota; and 150 will be positioned at F.E. Warren AFB, Wyoming (42:183,202,359,420).

Program Life. In accordance with the OSD CAIG *Operating and Support Cost-Estimating Guide*, the life expectancy for an ICBM program (to include the phase-in period) is twenty years (53:Ch 3,19-20). Under these guidelines, the O&S period is assumed to begin in the year 2000 and expire at the end of 2019.

FOT&E Activity Level. As noted previously, the initial test launch activity level is assumed to be ten flights per year for the last three years of DDT&E (17). Costs associated with these launches are covered in the DDT&E portion or our estimate. Once the booster enters the production and deployment phase of the acquisition process, test launch activity is assumed to be four flights per year for the remaining life of the program (57;17). These test launches are addressed in the O&S portion of our estimate.

Manpower Requirements. For operations (crew) personnel as well as direct and indirect support personnel, manpower requirements are assumed to be the same as the current requirements for the Minuteman III program. This assumption is based on the Phillips Laboratory constraint that the modified missiles will utilize existing Minuteman III equipment, facilities and silos (57). In our discussions with Ballistic Missile Organization cost analysis personnel, we could not justify any reasons for changing any Minuteman III manpower requirements to accommodate the booster modifications under consideration (28;17).

O&S Expected Savings. Because most of the O&S cost elements for the proposed designs are assumed to equal those for the current Minuteman III program, the only areas where measurable savings are expected to occur are under the depot maintenance portion of operations and support. More specifically, since the new designs will incorporate a newer guidance system and call for two solid rocket motors rather than three, differences in expected failure rates and depot repair costs for these particular items will account for most all of the savings between the proposed designs and the existing Minuteman III program.

LIFE-CYCLE COSTS OF ALTERNATIVE ICBM SECOND STAGE DESIGNS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYSTEMS AND LOGISTIC B D JOYCE ET AL. 2/2

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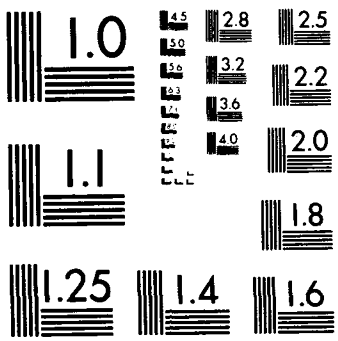
1.0
4.5
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5.0
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1.1
1.8
1.25
1.4
1.6

Cost Model Selection. Through our review of STACEM documentation, we determined this cost model was not acceptable for estimating the operating and support (O&S) costs of the alternative booster designs. Specifically, with respect to the O&S portion of the booster life-cycle, the STACEM database included only space launch vehicle cost figures (reference figure 2-13). Since support facilities and operations for space boosters greatly differ from those of silo-based ICBMs, the reliability of a STACEM generated ICBM O&S cost estimate would be questionable.

In our search to find a suitable approach to the O&S portion of our estimate we were referred to the Strategic Missile Cost Estimating (STRAMICE) model in AFR 173-13, *Cost Analysis* (22:128-131). Initially, we experienced difficulty obtaining a copy of this model because it was not included in the regulation after September 1986. Through discussion with Ballistic Missile Organization and Air Force Cost Analysis Agency personnel, we learned STRAMICE had been removed because it was no longer valid (54;17). In short, the model was not reliable because its cost factors were not updated on a regular basis (17).

Since the last printing of STRAMICE, only one new ICBM program has been introduced and seriously considered for acquisition by the Air Force: Small ICBM, or "Midgetman." Our review of the June 1991 O&S cost report for that program disclosed a STRAMICE derivative was the basis for the resulting estimate (27). We contacted members of the cost estimating team and learned that the STRAMICE shell can be quite useful in estimating Minuteman-related O&S costs, provided the cost factors are updated to reflect current conditions (28;17). For example, in the original STRAMICE model, estimates for depot maintenance cost elements (e.g., missile guidance system) were arrived at by multiplying the number of missiles deployed with an average annual cost per missile for repair of that element (22:128). This average per missile figure reflected 1986 Minuteman costs and conditions. It would be unreasonable to expect these factors have remained constant since that time. In the Small ICBM estimate, discrepancies such as these were overcome by obtaining current annual repair quantities and costs from the Ogden Air Logistics Center, where Air Force ICBMs are serviced. Other STRAMICE shortcomings were addressed through adjustments to the actual algorithms where it was believed accuracy could be improved.

Based on our research into the Small ICBM O&S cost estimate, we elected to use an adjusted STRAMICE model to support our estimate as well. Specifically, the following considerations lead to selection of this option:

1. The STRAMICE model closely parallels the generic Cost-Oriented Resource Estimating (CORE) model found in AFR 173-13 (Attachment 55 of the 23 August 1989 printing) as well as the missile O&S estimating structure prescribed in the May 1992 OSD Cost Analysis Improvement Group (CAIG) *Operating and*

Support Cost-Estimating Guide (53:App E). Therefore, adaptation of the old STRAMICE cost element structure would ensure our estimate addressed all pertinent aspects of the program operations and support phase and that it was consistent with current OSD and Air Force practices.

2. For all practical purposes, the Phillips Laboratory and AFIT engineering booster designs may be considered Minuteman III upgrades, or modifications. One can expect to find many similarities between the current Minuteman III program and the proposed designs with respect to operations and support. In fact, outside of minor changes, most support equipment, facilities, and manpower requirements should remain constant. As such, analogous system estimating techniques are justified. Since the example that accompanied STRAMICE indicated the model was developed around the Minuteman program, we concluded that this model could support analogous estimating procedures (22:128-131).

3. From our review of the Small ICBM O&S estimate documentation, and through discussion with Ballistic Missile Organization and Ogden ALC personnel, we determined current resource requirements could be readily obtained or interpolated to provide our Minuteman III O&S baseline and support an analogous estimate.

4. We were unable to identify any other Air Force sanctioned ICBM O&S cost models through our contacts with Space Systems Division, Aerospace Systems Division and the Ballistic Missile Organization. Furthermore, we discovered the processes involved with obtaining detailed historical O&S cost data for several missile programs to support a quantitative approach were beyond the scope of our research in terms of time and resources.

<u>Cost Model Calibration</u>. For reference purposes, the original STRAMICE O&S cost model from AFR 173-13 is reproduced in Appendix D. Detailed descriptions of the model's cost elements (also reproduced from AFR 173-13) are presented in Appendix E. The revised STRAMICE model, adjusted for our O&S estimating purposes, can be found in Appendix F. Justifications for our adjustments to the original STRAMICE are presented in this section. Please note that cost factor codes for the two models are not necessarily the same. For example, in the algorithms of the original STRAMICE, F61 represents enlisted turnover rate, whereas this factor is denoted by F50 in our adjusted model.

<u>Background</u>. To make the original STRAMICE model useful for our O&S estimating purposes, three types of adjustments were in order. The first type of adjustment involved updating cost factor inputs for inflation and current pay scales. For example, in the original model, the annual

operational ground test and analysis cost per missile was $15,116, in FY 1986 dollars. To express this rate in current dollars (FY 1992), this figure required adjustment to $18,570 per missile. Conversions such as this were made using the Air Force Cost Analysis Agency sanctioned Inflation Tutorial software.[1] In the case of personnel rate factors, adjustments were made based on the current pay scales in AFR 173-13. For example, in the 1986 STRAMICE, the weighted average officer pay rate was $55,422. Based on Table A19-1 of AFR 173-13, this figure was updated to $69,978 in 1992 dollars, for our estimating purposes.

Our second type of STRAMICE model alteration addressed the model inputs for manpower requirements. Specifically, in the example that accompanied the original model, the recommended manning inputs were based on a force of fifty Minuteman ICBMs (22:130). While the per missile ratios for direct (crew) personnel should still hold true at a force level of 500 missiles, it would be unreasonable to expect the indirect (support) personnel manning ratios to hold constant as well. As such, identification of indirect manpower requirements for a 500 missile fleet may be beyond the scope, or relevant range of the original model. In our opinion, the model's supporting documentation was not complete enough to

[1]This LOTUS based software incorporates current AFR 173-13 inflation indices and tables. The tutorial is available through the Air Force Cost Analysis Agency electronic bulletin board (1-800-344-3602) and it is the Air Force approved method for converting dollars from one year to another.

conclude otherwise. Therefore, we updated the STRAMICE manning inputs for a 500 missile fleet based on requirements presented in the silo-based scenario of the Small ICBM O&S cost estimate (27). Essentially, under the silo-based scenario, Small ICBM manpower requirements were assumed to match those for the current Minuteman III force (28). Since our program makes the same assumption, it was to our advantage to use these manning figures rather than expend a great deal of time recreating them ourselves. It should be noted that indirect manpower requirements for a particular program are not published in a readily available, consolidated form. Generally, these figures require a great deal of research, data collection and manipulation before they can be identified. Fortunately this task was already accomplished for us by Ballistic Missile Organization cost analysts in the Small ICBM O&S cost estimate (27).

The third and final type of change we incorporated in the model were adjustments to the original STRAMICE algorithms where it was believed estimating accuracy could be improved. Through review of the Small ICBM O&S estimate, we were able to identify and adopt some approaches that were simple, yet more representative of current conditions. For example, in the old model under depot maintenance, the estimated total annual cost of guidance repairs was arrived at by multiplying the number of deployed missiles with some average guidance repair cost per missile. This average repair cost was based on a force of fifty missiles in 1986. In our revised STRAMICE model, the total annual guidance repair cost is based on the current repair cost, known failure rates, and an adjustment for other than ordinary failures. These figures were obtained directly from involved personnel at the Ogden ALC. Since the original STRAMICE factors are outdated and the source cannot be identified, the results of our estimate should be more accurate and credible.

Specific Model Adjustments. As noted previously, inputs for manpower requirements in our revised version of STRAMICE (factors F1 through F31, Appendix F) were borrowed from the Small ICBM silo-based scenario cost estimate (27). The specific operations crew requirements (factor F5) were confirmed with the AFR 173-13 missile program factors table (A39-1, dated 29 February 1992).

In the revised model, the following cost factors were taken from the original STRAMICE model and converted to FY 1992 dollars using the Air Force Cost Analysis Agency Inflation Tutorial software:

F35, Motor Vehicle Fuel per Missile
F36, Maintenance Material per Missile
F37, Operations Material per Missile
F42, Operational Ground Test & Analysis Cost per Missile
F43, Operational Test & Analysis Cost per Launch
F45, Lease Expenses per Missile
F47, Other Contract Services per Missile

No other changes were made to these input values as it was assumed these factors would remain fairly constant between the Minuteman III program and the proposed boosters.

Cost factor F77 (2nd Destination Transportation and Helicopter Support per Missile) is a per missile aggregate of cost elements 5.5 and 5.6 from the original model. Actual cost inputs for these elements were not provided in the original model. However, through interpolation of the model's numeric example, we were able to determine the two elements together amounted to a projected annual cost of $571,000 in FY 1986 dollars, for a force of fifty missiles (22:129-131). We multiplied this figure by ten to correspond with a 500 missile force, converted it to FY 1992 dollars with the Inflation Tutorial, then divided by 500 to arrive at the per missile cost represented by factor F77. We chose to address the transportation and helicopter support cost elements through this single cost factor because the benefits of further detail would not have been worth the effort expended in obtaining that detail.

In Appendix F, the following revised cost factors were updated from the original STRAMICE model through use of current tables published in AFR 173-13:

Factor	AFR 173-13 Table	Date of Publication
F32, Officer Pay	A19-1	22 March 1991
F33, Enlisted Pay	A19-1	22 March 1991
F34, Civilian Pay	A28-1	22 March 1991
F49, Officer Turnover	A19-3	22 March 1991
F50, Enlisted Turnover	A19-3	22 March 1991
F56, Officer Acquisition	A17-1	29 March 1991
F57, Enlisted Acquisition	A17-1	29 March 1991

For some personnel cost factors, we were unable to find current (1992) values in the portions of AFR 173-13 available by electronic bulletin board. Since the source for these factors in the Small ICBM estimate was AFR 173-13, we applied values from the estimate after converting them to FY 1992 dollars (27). No other adjustments were made because it was reasonable to assume these values would remain constant between the Minuteman III program, the Small ICBM silo-based scenario, and the proposed booster program. The following factors were updated in this manner:

F46, Operational TDY Travel per Missile
F48, CCTS Cost per Graduate
F51, Installation Support Non-Pay
F52, Officer PCS (CONUS)
F53, Enlisted PCS (CONUS)
F54, Officer, Medical Non-Pay
F55, Enlisted, Medical Non-Pay
F58, Officer Specialty Training
F59, Enlisted Specialty Training

In the Small ICBM cost estimate, several cost factors were derived from historical Minuteman databases (27). Where possible, we adopted the corresponding values for the silo-based Small ICBM scenario (after converting them from FY 1991 to FY 1992 dollars with the Inflation Tutorial) rather than using values given in the original STRAMICE model. We elected this approach because the values were current, readily available, and their source was clearly established, documented and credible. The following revised factors were arrived at in this manner:

F38, Replenishment Spares per Missile
F39, Support Equipment per Missile
F40, Class IV Modifications per Missile
F41, Software Support per Missile
F44, Sustaining Engineering per Missile

Some factors in the Small ICBM estimate were based on both Minuteman and MX Peacekeeper databases (27). Again, we accepted these factors, after converting them to current dollars, as more reliable values than those in the original STRAMICE model. The factors concerned follow:

F62, Missile Repair Cost
F66, Support & Launch Mean Time Between Failure (MTBF)
F68, Support & Launch Cost per Repair
F69, Surface Command & Control MTBF
F71, Surface Command & Control Cost per Repair
F72, Annual Payload Maintenance per Missile
F73, Annual Software Maintenance per Missile
F74, Annual Trainer Maintenance per Missile
F75, Annual Depot Purchased Equipment (DPEM) cost per Missile

Through discussions with Ballistic Missile Organization and Ogden ALC personnel, we learned that ordinary item failures do not constitute the full depot repair workload (28;21). Activity associated with rework, test failures, induced failures, and false failures (RTOK: item retested okay) influence workload as well. The failure rates above (factors F66 and F69) do not capture this activity. In the Small ICBM estimate, this additional workload was addressed through logistics factors of eleven percent derived from historical Minuteman and Peacekeeper data (27:11-13). The specific factors are noted below and are incorporated in our model as well:

F61, Missile Logistics Factor
F67, Support & Launch Logistics Factor
F70, Surface Command & Control Logistics Factor

Up to this point, the STRAMICE factors we have derived, borrowed, or updated are assumed to be constant between the current Minuteman III program and that of the modified ICBMs. Four factors remain to be discussed. Attention is drawn to these factors since they are the only ones to vary between the two programs. These four factors will be the cause for differences in estimated O&S costs (the "delta" value). The factors in question are annual missile repair workload, guidance system repair cost, guidance system MTBF, and the guidance system logistics factor. Separate discussions of these factors, as they apply to the two missile programs, follow.

In our STRAMICE revision, annual missile repair workload is addressed by factor F60. For the Minuteman III baseline, the corresponding value was established as twelve missiles per year (43). Through discussion with Ogden ALC personnel, we learned the entire Minuteman III frame (the missile less post-boost vehicle, guidance and payload) must be shipped to depot in one piece for a failure on any one of the three stages (43). Furthermore, failures on the frame are almost always associated with accessories (e.g., actuators, wiring, electronics etc.), and most of these items are found on each stage (43). As such, we concluded that modification of a three stage missile to a two stage system should proportionally reduce the missile frame workload to two-thirds the baseline value. As a sanity check, this rationale was presented to and accepted by the AFIT engineering group. Therefore, the value assigned to the projected annual repair workload for the proposed designs (factor F60 in our revised STRAMICE model) was eight missiles.

Guidance system repair costs for factor F65 were obtained from Ogden ALC personnel (30). Through discussion we were informed that guidance repair costs are based on a negotiated rate, despite the work involved; even for RTOKs (21). At the time of our review, rates for the Minuteman III NS-20 guidance were under revision, but an approximate figure of $40,000 per repair was provided to us by the Ogden Program Control Office (30). Although the AIMS guidance system was still under development, a target cost of approximately $45,000 per repair was identified for that system (21;30).

For the Minuteman III NS-20 guidance system, we developed our own logistics multiplier (factor F64 in the revised STRAMICE). From discussions with the AFIT engineers and the Ogden Program Office, we established an NS-20 MTBF rate of approximately 12,000 hours (21). For the four and one half year period beginning January 1987, depot repair workload for this item averaged 427 annually. Given there are 500 NS-20 systems deployed and 8766 hours in a year (adjusted for leap years), we arrived at our logistics multiplier through the following computation:

$$\frac{\text{427 guidance repairs annually}}{\text{(500 systems x 8766 hours)/12,000 hour MTBF}} = 1.17$$

In the Small ICBM cost estimate, it was assumed the guidance system used would be the same as that for the MX Peacekeeper: the NS-30 (27). Based on historical Peacekeeper data, a logistics factor of 1.32 was used for guidance repair cost calculations (27:11-13). Because the AIMS system should rank up with the NS-30 in terms of complexity, we adopted the same logistics factor for the modified Minuteman estimate (21).

Although the AIMS guidance system Technical Requirements Document calls for a designed MTBF rate of at least 15,000 hours, the AFIT engineering group informed us that requirement has been upgraded to 20,000 hours (3:9). The latter value was incorporated in our O&S estimate (factor F63) for the proposed booster. As noted previously, the NS-20 MTBF for the Minuteman III baseline estimate was determined to be 12,000 hours.

Model Validation. In our first contacts with the Ballistic Missile Organization, before we acquired STRAMICE, we explained our objective and the related conditions and assumptions. At that time, one of their senior cost analysts gave us an annual O&S estimate (expert opinion) of $500 million for the Minuteman III program and told us to expect a similar rate for the proposed program (54). In the 1991 *ICBM Long Range Planning (ILRP) Minuteman Cost Data Report For OSD CAIG*, the Ogden ALC reported costs of $528 million for Minuteman III O&S (14:Table 2.3-1). As noted in Chapter V, when we ran our revised STRAMICE model with baseline Minuteman III constraints and factors discussed above, we arrived at an annual figure of $504.9 million. Unfortunately, we were unable to obtain supporting documentation for the Ogden cost report to reconcile the difference. However, since our results were off by less than five percent from both the Ogden and Ballistic Missile Organization Minuteman figures, they may be considered respectable. These results and a check of the logic used to update and derive our factors were the only tools available to measure our model's validity. Because analogous system estimating techniques were used to develop our revised STRAMICE model, formal model diagnostics could not be used to evaluate its performance.

Chapter Summary

This chapter identified the cost models chosen to estimate DDT&E, production, and operations and support costs for the proposed booster designs. Discussions related to the DDT&E and production portions of our estimates were presented first, followed by documentation of our operations and support cost efforts. Under both subjects, we outlined the assumptions associated with the proposed designs, our rationale for cost model selection, any model adjustments we made, and user determined input values for the models.

Chapter V
Cost Estimating Results

Chapter Overview

This chapter focuses on the results of our cost estimating efforts. Specifically, it presents our program design, development, test and evaluation (DDT&E) and production estimates for the alternative booster designs, as determined by the STACEM cost model. The one-time costs of booster integration (refitting) are then identified. Because of the similarity in designs from an operations and support perspective, one O&S estimate is presented for the two designs. Finally, for comparative purposes, a status quo Minuteman III baseline estimate is contrasted with total O&S figures under a conversion program where a constant force of 500 missiles is maintained. ***Years cited in this chapter are fiscal years (FY) and all cost figures presented are expressed in FY 1992 dollars.***

DDT&E and Production Costs

DDT&E and production cost schedules and estimates for the two proposed booster designs are presented on the next four pages. These estimates were generated by STACEM and are based on the assumptions and inputs outlined in this chapter and Chapter IV.

Phillips Laboratory Booster
DDT&E and Production Cost Breakdown Totals
FY 1992, $Millions

CBS Number	Cost Category	Amount $Million	Percent of total
0	Total DDT&E and Production Cost:	990.036	
1.	Solid Rocket Booster Production:	824.678	83.30
1.01	.Electrical & instrumentation	41.650	4.21
1.02	.Separation system	8.631	.87
1.03	.Structures	11.407	1.15
1.04	.Solid rocket motor	418.711	42.29
1.04.1	..Case	106.384	10.75
1.04.2	..Insulation	14.655	1.48
1.04.3	..Liner	1.063	.11
1.04.4	..Solid fuel	110.269	11.14
1.04.5	..Nozzle	120.264	12.15
1.04.6	..Thrust vector control	24.716	2.50
1.04.7	..Ignition system	4.707	.48
1.04.8	..Preship-assembly & checkout	12.150	1.23
1.04.9	..Additional motor-level items	24.504	2.48
1.05	.Flight recovery equipment	.000	.00
1.06	.Shipping and logistics	2.043	.21
1.07	.Booster program support	56.832	5.74
1.08	.Additional booster-level items	82.507	8.33
1.09	.Overall systems support	41.677	4.21
1.10	.Additional G&A and fees	161.220	16.28
1.10.1	..General & Administrative	66.346	6.70
1.10.2	..Fees	94.874	9.58
5.	DDT&E	165.358	16.70
5.01	.Stage engineering	12.667	1.28
5.02	.Propulsion	18.859	1.90
5.03	.Training	585	.06
5.04	.Test hardware	16.073	1.62
5.05	.Test operations	69.049	6.97
5.06	.Facilities	39.880	4.03
5.07	.Ground support equipment	1.261	.13
5.08	.System integration	6.335	.64
5.09	.Tooling	.478	.05
5.10	.Additional G&A and fees	.170	.02
5.10.1	..General & Administrative	.096	.01
5.10.2	..Fees	.075	.01

Phillips Laboratory Booster
DDT&E and Production Outlay Schedule
FY 1992, $Millions

Year	DDT&E	Procurement	Total
1992	0	0	0
1993	0	0	0
1994	43.883	0	43.883
1995	31.560	0	31.560
1996	31.560	0	31.560
1997	19.236	0	19.236
1998	19.236	0	19.236
1999	19.236	0	19.236
2000	54	85.757	85.811
2001	54	79.125	79.179
2002	54	76.202	76.256
2003	54	74.334	74.388
2004	54	72.967	73.021
2005	54	71.893	71.947
2006	54	71.011	71.065
2007	54	70.264	70.318
2008	54	69.617	69.671
2009	54	69.047	69.101
2010	54	68.538	68.592
2011	54	15.925	15.979
Total:	165.358	824.678	990.036

AFIT Engineering Booster
DDT&E and Production Cost Breakdown Totals
FY 1992, $Millions

CBS number	Cost Category	Amount $Million	Percent of Total
0	Total DDT&E and Production Cost:	743.274	100.00
1.	Solid Rocket Booster Production:	646.663	87.00
1.01	.Electrical & instrumentation	41.650	5.60
1.02	.Separation system	8.631	1.16
1.03	.Structures	11.407	1.53
1.04	.Solid rocket motor	347.394	46.74
1.04.1	..Case	107.238	14.43
1.04.2	..Insulation	14.435	1.94
1.04.3	..Liner	.956	.13
1.04.4	..Solid fuel	110.663	14.89
1.04.5	..Nozzle	67.097	9.03
1.04.6	..Thrust vector control	25.663	3.45
1.04.7	. Ignition system	3.113	.42
1.04.8	..Preship-assembly & checkout	7.449	1.00
1.04.9	..Additional motor-level items	10.778	1.45
1.05	.Flight recovery equipment	.000	.00
1.06	.Shipping and logistics	1.376	.19
1.07	.Booster program support	34.650	4.66
1.08	.Additional booster-level items	49.727	6.69
1.09	.Overall systems support	25.410	3.42
1.10	.Additional G&A and fees	126.419	17.01
1.10.1	..General & Administrative	52.024	7.00
1.10.2	..Fees	74.395	10.01
5.	DDT&E	96.611	13.00
5.01	.Stage engineering	7.600	1.02
5.02	.Propulsion	11.416	1.54
5.03	.Training	.351	.05
5.04	.Test hardware	8.819	1.19
5.05	.Test operations	41.429	5.57
5.06	.Facilities	23.928	3.22
5.07	.Ground support equipment	.456	.06
5.08	.System integration	2.256	.30
5.09	.Tooling	.262	.04
5.10	.Additional G&A and fees	.093	.01
5.10.1	..General & Administrative	.052	.01
5.10.2	..Fees	.041	.01

AFIT Engineering Booster
DDT&E and Production Outlay Schedule
FY 1992, $Millions

Year	DDT&E	Procurement	Total
1992	0	0	0
1993	0	0	0
1994	25.610	0	25.610
1995	18.434	0	18.434
1996	18.434	0	18.434
1997	11.259	0	11.259
1998	11.259	0	11.259
1999	11.259	0	11.259
2000	.030	67.245	67.275
2001	.030	62.045	62.075
2002	.030	59.753	59.783
2003	.030	58.288	58.317
2004	.030	57.216	57.246
2005	.030	56.374	56.404
2006	.030	55.683	55.712
2007	.030	55.097	55.126
2008	.030	54.589	54.619
2009	.030	54.142	54.172
2010	.030	53.743	53.773
2011	.030	12.487	12.517
Total:	96.611	646.663	743.274

As evidenced by the estimates presented on the preceding pages, costs for booster DDT&E and production varied significantly between the Phillips Laboratory and AFIT engineering designs. Phillips Laboratory design costs were higher in most of the cost categories. Values assigned to complexity factors and component weights accounted for most of these differences. Overall, Phillips Laboratory personnel felt their design was more complex, and merited higher complexity ratings. As noted previously, complexity factors are subjective and are only as reliable as the judgement of those queried. Specific differences in the cost estimates are addressed in the following discussions. For reference purposes, the related cost estimating relationships are listed in Appendix B.

<u>Design, Development, Test, and Evaluation</u>. The complexity factor assigned to research, development, and testing is the major contributor to differences in cost estimates for this phase of the life-cycle. The complexity factor/multiplier used by the AFIT engineers was .6, while the Phillips Laboratory design complexity factor/multiplier was 1. Consequently, all cost categories for the AFIT design were adjusted (reduced) by forty percent. For the first three sub-categories (stage engineering, propulsion, and training), and the test operations and facilities sub-categories, only complexity factors differed between designs. Detailed

descriptions of these cost categories are provided in Appendix A.

Differences in individual booster component weights accounted for some of the gap in estimated costs under the test hardware and tooling sub-categories. Key components were the motor case, insulation, and propellant. Between these three components, the difference in design weights amounted to 517 pounds. Because the AFIT booster was the lighter design, this difference in weights only caused estimated costs to diverge further.

Since the costs of ground support equipment, system integration, fees, and general and administration charges are based on percentages of those costs discussed above, these categories further aggravated the difference in estimates.

For both designs, the largest cost categories in the DDT&E phase of the life-cycle are the test operations and facilities. In both cases, costs associated with test operations accounted 40-43 percent of the total DDT&E cost, while the facilities category account for approximately twenty-five percent of the cost.

<u>Production</u>. As stated earlier, the complexity factors assigned to the different categories played a key role in the divergence of costs between the two designs. Phillips Laboratory personnel consistently rated their design more complex; therefore, their overall estimated cost was significantly higher.

The first three production cost sub-categories (electrical and instrumentation, separation system, and structures) were the same between designs because both assumed current Minuteman III values for the related variables. As such, the complexity factors and component weights used were identical for both boosters.

Under STACEM, the next set of production cost categories addressed the solid rocket motor and individual components of the motor. Differences in individual component weights, and complexity factor ratings contributed to a variations in cost here also.

Under the production phase of STACEM, shipping and logistics costs were a function of total motor weight. Total booster weight, total impulse, and average thrust were factors in the cost of the booster program support and overall system support cost categories. The "additional booster level items" cost category was a function of the total booster weight, the number of motors produced, and the learning rate. Estimates for general and administration (G&A) charges were determined by taking a percent of the sum of all production costs calculated to this point. Finally, fees (contractor profit) were calculated as a percentage of all these costs including the general and administrative costs. It should be noted that STACEM estimates figures for G&A and fees in this manner, based on historical patterns. In reality, fees are generally negotiated at some fixed amount since they cannot be cost dependent under DoD guidelines.

It was not surprising that the largest cost categories under the production phase were administrative costs and solid rocket motors. Administrative costs accounted for approximately twenty percent of all costs for this phase. The solid rocket motor cost category accounted for over fifty percent of the total costs. Major cost sub-categories for the solid rocket motor were the case (approximately 25 to 30 percent of the motor production cost), the propellant (approximately 26 to 32 percent of the cost), and the nozzle (approximately 20 to 30 percent of the motor production cost).

As noted previously, total DDT&E and production costs for the AFIT engineering design were approximately $743.274 million. Average unit cost of each of the 674 solid rocket motors was roughly $1.1 million. Total DDT&E and production cost for the Phillips Laboratory design was estimated at $990.036 million. This equates to an average unit cost of approximately $1.46 million. Because unit costs include a fixed overhead component, one can expect these costs to increase if fewer than 674 motors are produced. In this case, fewer motors would be available to absorb the fairly fixed DDT&E and production set-up costs.

Booster Integration Costs

Integration of the proposed booster with Minuteman III components is assumed to occur at the Ogden logistics center. Costs associated with this one-time effort include missile breakdown, buildup and roundtrip transportation. The estimated cost of breakdown and buildup was $50,000 per missile. This recycling cost was based on the expert opinion of a Minuteman III production manager (43). The roundtrip transportation figures used were the actual rates charged for the Minuteman III. These rates are station dependent and are listed below (20):

Minot AFB, ND - Hill AFB, UT:	$27,616
Grand Forks AFB, ND - Hill AFB, UT:	$27,616
F.E. Warren AFB, WY - Hill AFB, UT:	$ 8,253
Malstrom AFB, MT - Hill AFB, UT:	$24,172

To arrive at the booster integration costs, we multiplied the number of missiles at each base with the sum of the recycling and roundtrip transportation costs. These cost would be incurred during the program phase-in period (2000 - 2010), according to the missile wing conversion schedule (unknown at the time of our review). Calculations for the total estimated integration costs follow:

Minot AFB:	150 x ($50,000 + $27,616) = $11,642,400
Grand Forks AFB:	150 x ($50,000 + $27,616) = $11,642,400
F.E. Warren AFB:	150 x ($50,000 + $ 8,253) = $ 8,737,950
Malstrom AFB:	50 x ($50,000 + $24,172) = $ 3,708,600
Total Estimated Integration Costs:	$35,731,350

Operations and Support Costs

The O&S cost model and factors used to generate our estimate were discussed in Chapter IV. The actual model, factors, and resulting steady-state O&S estimates for both the Minuteman III baseline and the modified booster are presented in Appendix F. The results in Appendix F are summarized below. As noted in Chapter IV, the same O&S estimate for a two-stage Minuteman applies to both booster designs.

Minuteman III Steady-State O&S Estimate

	Cost Element	Annual O&S Dollars in Millions
1	Unit Mission Personnel	$213.545
2	Unit Level Consumption	$10.518
3	Depot Maintenance	$79.016
4	Sustaining Investment	$26.027
5	Other Direct Costs	$82.380
6	Installation Sup. Personnel	$26.578
7	Indirect Personnel Support	$58.724
8	Acquisition & Training	$8.155
	TOTAL:	$504.943

Two-Stage Minuteman Steady-State O&S Estimate

	Cost Element	Annual O&S Dollars in Millions
1	Unit Mission Personnel	$213.545
2	Unit Level Consumption	$10.518
3	Depot Maintenance	$74.416
4	Sustaining Investment	$26.027
5	Other Direct Costs	$82.380
6	Installation Sup. Personnel	$26.578
7	Indirect Personnel Support	$58.724
8	Acquisition & Training	$8.155
	TOTAL:	$500.344

Based on the deployment schedule outlined in Chapter IV, we computed O&S costs for each year of the program's twenty year service life. Design specific O&S costs for a particular year were calculated as a fraction of the steady-state rate above, in proportion to the cumulative number of two-stage missiles activated. The calculations and resulting O&S

schedule are presented below. *These figures do not include O&S costs related to the Minuteman III ICBMs maintained during phase-in to keep a constant force of 500.*

20 Year Operations and Support Costs
Two-Stage Minuteman ICBM Fleet

Year	Boosters Activated	Cum. Force	Weighted-Average Operating and Support Cost
2000	20	20	20/500 x $500.344 = $ 20.014
2001	53	73	73/500 x $500.344 = $ 73.050
2002	53	126	126/500 x $500.344 = $ 126.087
2003	53	179	179/500 x $500.344 = $ 179.123
2004	53	232	232/500 x $500.344 = $ 232.160
2005	53	285	285/500 x $500.344 = $ 285.196
2006	53	338	338/500 x $500.344 = $ 338.233
2007	53	391	391/500 x $500.344 = $ 391.269
2008	53	444	444/500 x $500.344 = $ 444.305
2009	53	497	497/500 x $500.344 = $ 497.342
2010	3	500	500/500 x $500.344 = $ 500.344
2011		500	500/500 x $500.344 = $ 500.344
2012		500	500/500 x $500.344 = $ 500.344
2013		500	500/500 x $500.344 = $ 500.344
2014		500	500/500 x $500.344 = $ 500.344
2015		500	500/500 x $500.344 = $ 500.344
2016		500	500/500 x $500.344 = $ 500.344
2017		500	500/500 x $500.344 = $ 500.344
2018		500	500/500 x $500.344 = $ 500.344
2019		500	500/500 x $500.344 = $ 500.344
Total Estimated Program O&S Costs ($millions):			$7,590.219

Comparison of Status Quo and Mixed Force O&S

For the designs under review, the status quo alternative is an unchanged Minuteman III fleet of 500 missiles, maintained through the year 2019. To form a basis of comparison between O&S costs under the status quo and those for the two-stage designs, we viewed the proposed modifications as a continuation of the Minuteman III program.

In that respect, annual O&S costs during the twenty year life require a component for two-stage missiles and one for the remaining Minuteman IIIs, until conversion of all 500 missiles is complete. Up to that point, annual O&S costs address a mixed force of 500 missiles.

Operations and support cost under the mixed force concept were determined by summing the weighted-averages of the annual steady-state O&S estimates previously noted on page 5-11. For example, in the second year of operations (2001), a total of 73 two-stage missiles will be in service. To maintain a constant force of 500 missiles, 427 Minuteman IIIs will remain deployed. The O&S costs associated with this mixed force were determined as follows:

Two-stage missiles:	(73/500) x $500.344 million
Minuteman IIIs:	+ (427/500) x $504.943 million
Total O&S, FY 2001:	$504.272 million

The resulting twenty year operations and support cost schedule for the mixed Minuteman fleet is presented on the following page. In the scenario presented, the constant outlays associated with steady-state operations begin with the year 2010 and continue through the end of fiscal year 2019.

20 Year Operations and Support Costs
Mixed Minuteman ICBM Fleet

Year	2-Stage Missiles Deployed	2-Stage Missile O&S Cost	MM III Missiles Deployed	MM III O&S Cost	Mixed Force O&S Cost
2000	20	$ 20.014	480	$484.745	$504.759
2001	73	$ 73.050	427	$431.221	$504.272
2002	126	$126.087	374	$377.697	$503.784
2003	179	$179.123	321	$324.173	$503.297
2004	232	$232.160	268	$270.649	$502.809
2005	285	$285.196	215	$217.125	$502.322
2006	338	$338.233	162	$163.602	$501.834
2007	391	$391.269	106	$110.078	$501.347
2008	444	$444.305	56	$ 56.554	$500.859
2009	497	$497.342	3	$ 3.030	$500.372
2010	500	$500.344	0	$ 0.000	$500.344
2011	500	$500.344	0	$ 0.000	$500.344
2012	500	$500.344	0	$ 0.000	$500.344
2013	500	$500.344	0	$ 0.000	$500.344
2014	500	$500.344	0	$ 0.000	$500.344
2015	500	$500.344	0	$ 0.000	$500.344
2016	500	$500.344	0	$ 0.000	$500.344
2017	500	$500.344	0	$ 0.000	$500.344
2018	500	$500.344	0	$ 0.000	$500.344
2019	500	$500.344	0	$ 0.000	$500.344

Total Estimated
Mixed Fleet O&S Costs ($millions): $10,029.093

Based on the Minuteman III steady-state estimate of annual O&S expenditures, the cost of the status quo alternative is $10,098.86 million (20 years x $504.943 million per year). This assumes no dramatic life extension measures are undertaken. The total estimated O&S savings of adopting one of the proposed two-stage booster designs is $69.767 million ($10,098.860 million - $10,029.093 million).

To determine where specific cost savings would be realized, we analyzed cost elements 3.1 and 3.2 (missile and guidance depot maintenance) and the related cost factors for the revised STRAMICE cost model (Appendix F). Our review disclosed that 88.6 percent of the annual steady-state O&S savings was attributable to the AIMS guidance assumption noted on page 4-12. Reductions in depot missile repair workload for a two-stage system accounted for the remaining 11.4 percent of the savings. These percentages hold constant for the twenty year O&S comparison as well. Consequently, of the estimated $69.767 million in savings over the proposed missile's operational life, $61.824 million would be related to the AIMS guidance and $7.943 million would be due to the two-stage design.

Chapter Summary

This chapter highlighted the results of our cost estimating efforts. It presented our program design, development, test and evaluation (DDT&E) and production estimates for the alternative booster designs, as determined by the STACEM cost model. The one-time costs of booster integration (refitting) were then identified. Using our revised STRAMICE model and simple weight-average techniques, we produced one O&S cost schedule for both design proposals. Finally, a status quo Minuteman III baseline estimate was contrasted with total O&S figures under a conversion program scenario where a constant force of 500 missiles was maintained over the program life. Years cited in this chapter were fiscal years and all cost figures presented were expressed in FY 1992 dollars.

Appendix A

STACEM Variable Descriptions

VARIABLE NAME	DESCRIPTION/VALUE.....
1.	INCLUDES ALL LABOR AND MATERIAL NECESSARY TO COMPLETE THE PRIMARY ELEMENT OF THIS WORK BREAKDOWN STRUCTURE (WBS). IT INCLUDES ALL ITEMS REQUIRED TO DELIVER FLIGHT CERTIFIED SRB COMPONENTS AND ASSEMBLIES TO LAUNCH ASSEMBLY STATIONS. LAUNCH SITE OPERATION COSTS ARE NOT INCLUDED IN THIS WBS ITEM. THE CER VALUE OF THIS ELEMENT IS THE NUMERIC SUM OF ELEMENTS 1.01, 1.02, 1.03, 1.04, 1.05, 1.06, 1.07, 1.08, 1.09 AND 1.10.
1.01	ELECTRICAL AND INSTRUMENTATION INCLUDES LABOR AND MATERIAL COSTS ASSOCIATED WITH RANGE SAFETY SYSTEM, ELECTRICAL SYSTEMS, ON-BOARD INSTRUMENTATION AND FLIGHT CONTROL, TELEMETRY EQUIPMENT, DESTRUCT SYSTEM, AND INITIATOR.
1.02	SEPARATION SYSTEM INCLUDES LABOR AND MATERIAL COSTS ASSOCIATED WITH THE MANUFACTURE AND FINAL ASSEMBLY OF THE ELECTRONICS, CONTROLS, MOTORS, AND IGNITERS OF THE SEPARATION SYSTEM. THIS INCLUDES THE COST OF ASSEMBLY AND ATTACHMENT TO THE SRB. IT ALSO INCLUDES ALL MECHANICAL AND ELECTRICAL SUB-ASSEMBLIES TO THE SEPARATION SYSTEM.
1.03	STRUCTURES INCLUDES THE LABOR AND MATERIAL COSTS ASSOCIATED WITH THE MAJOR SUB-ASSEMBLIES OF THE SRB. FOR EXAMPLE, THE NOSE CONE ASSEMBLY, FORWARD AND AFT CLOSURES, ATTACHING STRUCTURES AND STRUTS, FORWARD AND AFT SKIRTS AND ALL SYSTEMS TUNNEL OR RACEWAYS. THIS ITEM DOES NOT INCLUDE ANY FACILITY MODIFICATIONS REQUIRED TO SUPPORT THE NEW SRB.
1.04	SOLID ROCKET MOTOR (SRM) INCLUDES ALL ELEMENTS OF THE SRM PRODUCTION CYCLE UP UNTIL THE DELIVERY OF THE MOTOR TO THE SYSTEM INTEGRATOR. INCLUDING ALL RECURRING COSTS SUCH AS RECURRING ENGINEERING, SUSTENANCE TOOLING, MANUFACTURING, PURCHASED EQUIPMENT, QUALITY CONTROL AND NORMAL CHANGE ORDERS. IT DOES NOT INCLUDE GENERAL AND ADMINISTRATIVE AND PROFIT. THE CER VALUE OF THIS ELEMENT IS

VARIABLE NAME	DESCRIPTION/VALUE.....
	THE NUMERIC SUM OF THE ELEMENTS 1.04.1, 1.04.2, 1.04.3, 1.04.4, 1.04.5, 1.04.6, 1.04.7, 1.04.8, AND 1.04.9.
1.04.1	CASE INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO PRODUCE THE CASE (WHICH CONTAINS THE PROPELLANT BEFORE AND AFTER THE DEFLAGRATION PROCESS), INCLUDING THE FORWARD AND AFT CLOSURES.
1.04.2	INSULATION INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO PRODUCE CASE INSULATION, RELIEF FLAPS, FACING INHIBITORS, AND OTHER ITEMS DESIGNED TO PROTECT COMPONENTS FROM, OR CONTROL THE DIRECTION OF, THE PROPELLANT BURN.
1.04.3	LINER INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO PRODUCE THE BOND BETWEEN THE PROPELLANT AND THE INSULATION.
1.04.4	PROPELLANT INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO TEST, PRODUCE, AND LOAD THE COMBUSTIBLE MATERIAL WHICH PROVIDES CHEMICAL ENERGY FOR THE SRB.
1.04.5	NOZZLE INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO PRODUCE THE CONVERGENT-DIVERGENT DEVICE THAT DIRECTS THE KINETIC RELEASE OF THE CHEMICAL FUEL. THE NOZZLE MAY BE MOVABLE OR RIGID, CANTED OR UNCANTED, EXTENDABLE OR FIXED, EXTERNAL OR SUBMERGED. THE NOZZLE ASSEMBLY GENERALLY CONSISTS OF A THROAT ASSEMBLY, EXIT CONE, EXTENSION CONE, AND A NOZZLE/CASE INTERFACE.
1.04.6	TRUST VECTOR CONTROL INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO PRODUCE THE DEVICE THAT CONTROLS PITCH, ROLL AND YAW FOR THE SRB PORTION OF THE LAUNCH VEHICLE.
1.04.7	IGNITION SYSTEM INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO PRODUCE THE IGNITION SYSTEM. IT IS TYPICALLY COMPOSED OF A SAFE AND ARM DEVICE, AN IGNITER INITIATOR, AND THE IGNITER ITSELF, TYPICALLY A PYROGEN ASSEMBLY.

VARIABLE NAME	DESCRIPTION/VALUE.....
1.04.8	PRE-SHIP ASSEMBLY AND CHECKOUT INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING ASSOCIATED WITH PACKAGING, TESTING AND
1.04.8	SHIPPING THE COMPLETED SRM FROM THE SITE OF PRODUCTION TO THE SITE OF SRB INTEGRATION.
1.04.9	ADDITIONAL MOTOR LEVEL ITEMS INCLUDES ALL LABOR, MATERIAL AND SUSTENANCE TOOLING NECESSARY TO COMPLETE THE SRM NOT INCLUDED IN WBS ITEMS 1.04.1, 1.04.2, 1.04.3, 1.04.4, 1.04.5, 1.04.6, 1.04.7 AND 1.04.8.
1.05	FLIGHT RECOVERY EQUIPMENT INCLUDES ALL MATERIAL AND LABOR ASSOCIATED WITH ON-BOARD FLIGHT RECOVERY EQUIPMENT INCLUDING PYROTECHNICS, PARACHUTES, DEPLOYMENT ORDNANCE, RADIO BEACONS, FLOTATION DEVICES AND RELATED OTHER EQUIPMENT NECESSARY FOR SRB RECOVERY OPERATIONS.
1.06	SHIPPING AND LOGISTICS INCLUDES ALL LABOR AND MATERIAL EXPENDED IN THE PACKING, TRANSPORTATION, STORAGE, SPECIAL HANDLING AND LOGISTICAL SUPPORT OF BOOSTERS FROM THE POINT OF MANUFACTURE TO THE POINT OF LAUNCH.
1.07	BOOSTER PROGRAM SUPPORT INCLUDES ALL LABOR AND MATERIAL ASSOCIATED WITH THE ACCEPTANCE TESTS, RECURRING ENGINEERING, AND SPECIAL TOOLING AND EQUIPMENT ASSOCIATED WITH THE SRB.
1.08	ADDITIONAL BOOSTER LEVEL ITEMS INCLUDES ALL LABOR AND MATERIAL NECESSARY TO COMPLETE THE SRB NOT INCLUDED IN WBS ITEMS 1.01, 1.02, 1.03, 1.04, 1.05, 1.06, AND 1.07.
1.09	OVERALL SYSTEMS SUPPORT INCLUDES ALL OVERHEAD COSTS ASSOCIATED WITH COMPLETE MANUFACTURE OF THE SRB. THIS INCLUDES ON-GOING ENGINEERING SUPPORT, PROJECT MANAGEMENT, SPARES SUPPORT, QUALITY ASSURANCE, AND OTHER SUPPORT ACTIVITIES. ALL SUPPORT ACTIVITIES NOT INCLUDED IN 1.07 ARE INCLUDED HERE.
1.10	ADDITIONAL GENERAL AND ADMINISTRATIVE AND FEE CHARGES INCLUDES ALL G&A CHARGES AND FEE ASSOCIATED WITH ALL ASPECTS OF THE PRODUCTION PHASE OF THE SRB LIFE CYCLE.

VARIABLE NAME	DESCRIPTION/VALUE.....
1.10.1	ADDITIONAL GENERAL AND ADMINISTRATIVE CHARGES INCLUDES ALL G&A CHARGES ASSOCIATED WITH ALL ASPECTS OF THE PRODUCTION PHASE OF THE SRB LIFE CYCLE.
1.10.2	ADDITIONAL FEE CHARGES INCLUDES ALL FEES ASSOCIATED WITH ALL ASPECTS OF THE PRODUCTION PHASE OF THE SRB LIFE CYCLE.
5.	DESIGN, DEVELOPMENT TESTING AND ENGINEERING THIS COST ELEMENT INCLUDES ALL EFFORTS INVOLVED IN THE DESIGN, DEVELOPMENT, TEST, ENGINEERING, AND EVALUATION OF THE SRB SYSTEM. FOR THE DESIGN AND DEVELOPMENT PHASE THIS INCLUDES THE COSTS FOR SYSTEMS ENGINEERING, DATA, MANUALS, REPORTS, DRAWINGS, LISTS AND SPECIFICATIONS AS WELL AS THE DEVELOPMENT OF PROTOTYPE SYSTEMS. THE TEST AND INTEGRATION REFERS TO THE APPLICATION APPLIED AGAINST PROTOTYPE, PRODUCTION AND SPECIALLY FABRICATED HARDWARE TO VALIDATE ENGINEERING DATA ON SRB PERFORMANCE. THIS COST ELEMENT ALSO INCLUDES THE DESIGN AND CONSTRUCTION OF ALL REQUIRED FACILITIES AND THE DESIGN AND MANUFACTURE OF ALL GROUND SUPPORT EQUIPMENT REQUIRED TO SUPPORT THE SRB PROGRAM EXCEPT THE FACILITIES AND GROUND SUPPORT EQUIPMENT AT THE LAUNCH SITE. THOSE ITEMS ARE COVERED IN WBS 2.0. THE CER VALUE OF THIS ELEMENT IS THE NUMERIC SUM OF ELEMENTS 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, AND 5.10.
5.01	STAGE ENGINEERING INCLUDES ALL LABOR AND MATERIAL NECESSARY TO SUPPORT ENGINEERING, DESIGN, AND DEVELOPMENT OF STRUCTURAL COMPONENTS AND RECOVERY SYSTEM EQUIPMENT ATTACHED TO EACH MOTOR. SEE WBS 1.03 FOR A DESCRIPTION OF THESE COMPONENTS.
5.02	PROPULSION INCLUDES ALL LABOR AND MATERIAL NECESSARY TO SUPPORT PRIMARY SRM DESIGN AND ANY SECONDARY (ABORT OR SEPARATION) MOTOR DESIGN. THIS TASK CONSISTS OF ENGINEERING DESIGN AND DEVELOPMENT OF THE SOLID MOTOR CASE, INSULATION, NOZZLE, PROPELLENT, LINER, TVC AND ACCESSORIES. IT INCLUDES THE COST FOR FABRICATION OF PRELIMINARY FLIGHT RATING TEST MOTORS.

VARIABLE NAME	DESCRIPTION/VALUE.....
5.03	TRAINING INCLUDES ALL LABOR AND MATERIAL NECESSARY TO INSTRUCT AND TRAIN PERSONNEL TO MAINTAIN, ASSEMBLE, AND CHECKOUT BOOSTER VEHICLES.
5.04	TEST HARDWARE INCLUDES ALL LABOR AND MATERIAL NECESSARY TO SUPPORT ALL HARDWARE REQUIREMENTS IN THE DDT&E PHASE.
5.05	TEST OPERATIONS INCLUDES ALL LABOR AND MATERIAL NECESSARY TO SUPPORT SYSTEMS DEVELOPMENT TESTS USING PROTOTYPE HARDWARE TO ACQUIRE ENGINEERING DATA AND CONFIRM ENGINEERING HYPOTHESES. TEST OPERATIONS COSTS INCLUDE THOSE FOR DETAIL PLANNING, SUPPORT, DATA ACQUISITION AND ANALYSIS, GOVERNMENT REPORTING, AND FLIGHT TESTING.
5.06	FACILITIES INCLUDES ALL LABOR AND MATERIAL NECESSARY TO CONSTRUCT AND MAINTAIN NEW FACILITIES AND/OR THE MODIFICATION OF EXISTING FACILITIES REQUIRED TO MANUFACTURE AND INSPECT THE SRB AND ITS COMPONENTS. THIS DOES NOT INCLUDE THE FACILITIES ASSOCIATED WITH LAUNCH OPERATIONS AT THE LAUNCH SITE.
5.07	GROUND SUPPORT EQUIPMENT INCLUDES ALL LABOR AND MATERIAL NECESSARY TO SUPPORT VENDOR AND MOTOR MANUFACTURER WITH GROUND SUPPORT EQUIPMENT FOR THE TRANSPORT, HANDLING, AND TESTING OF THE COMPLETED SRB. THIS DOES NOT INCLUDE THE GROUND SUPPORT EQUIPMENT ASSOCIATED WITH LAUNCH OPERATIONS AT THE LAUNCH SITE.
5.08	SYSTEM INTEGRATION INCLUDES ALL LABOR AND MATERIAL NECESSARY TO SUPPORT OVERALL INTEGRATION OF DEVELOPMENT ACTIVITIES. INCLUDED ARE ESTABLISHMENT OF ENGINEERING DESIGN CHARACTERISTICS, DETERMINATION OF CRITERIA FOR DESIGN REVIEW, ESTABLISHMENT OF PROCEDURES FOR TESTING COMPONENTS, SUBSYSTEMS OR SRM ELEMENTS, INTEGRATION OF GROUND AND FLIGHT TEST RESULTS INTO BOOSTER DESIGN, DEVELOPMENT OF MAINTENANCE PROCEDURES AND QUALITY ASSURANCE ENGINEERING PLANNING.

VARIABLE NAME	DESCRIPTION/VALUE.....
5.09	TOOLING INCLUDES ALL LABOR AND MATERIAL NECESSARY TO SUPPORT INITIAL TOOLING REQUIREMENTS FOR THE SRB. IT COVERS PLANNING, DESIGN, MAINTENANCE AND REWORK OF ALL HARD AND SOFT TOOLS INCLUDING SPECIALIZED ASSEMBLY TOOLS, DIES, FIXTURES, GAUGES, AND HANDLING EQUIPMENT. INCLUDED ARE COSTS OF TOOLING REQUIREMENTS STUDIES, SPECIFICATIONS, SCHEDULING, PROGRAMMING AND FABRICATION COSTS. THIS ITEM DOES NOT INCLUDE SUSTENANCE TOOLING OR RATE TOOLING.
5.10	ADDITIONAL GENERAL AND ADMINISTRATIVE AND FEE CHARGES INCLUDES ALL G&A CHARGES AND FEES ASSOCIATED WITH ALL ASPECTS OF THE DDT&E PHASE OF THE SRB LIFE CYCLE.
5.10.1	ADDITIONAL GENERAL AND ADMINISTRATIVE CHARGES INCLUDES ALL G&A CHARGES ASSOCIATED WITH ALL ASPECTS OF THE DDT&E PHASE OF THE SRB LIFE CYCLE.
5.10.2	ADDITIONAL FEE CHARGES INCLUDES ALL FEES ASSOCIATED WITH ALL ASPECTS OF THE DDT&E PHASE OF THE SRB LIFE CYCLE.
APX11-APX5	COMPLEXITY FACTORS. THESE FACTORS REFLECT THE TECHNOLOGICAL COMPLEXITY OF THE SRB PROGRAM BEING ANALYZED. THE TECHNOLOGICAL COMPLEXITY INCLUDES MATERIALS, PROCESSING, AND LABOR. THE NUMBERS IN THE VARIABLE NAME REFER TO THE SPECIFIC CER, OR CERS IN THE CASE OF APX5, IN WHICH THE FACTOR IS USED. ADDITIONAL RESEARCH AND DEVELOPMENT IS NEEDED TO DETERMINE APPLICABLE FACTORS FOR SYSTEMS WHICH DO NOT HAVE THE SAME COMPLEXITY AS THE SYSTEMS USED TO DEVELOP THE CURRENT COST ESTIMATING RELATIONSHIPS. (INDEPENDENT, SCALAR)

VARIABLE NAME	DESCRIPTION/VALUE.....
APX11	1.0 : ELECTRICAL & INSTRUMENTATION
APX12	1.0 : SEPARATION SYSTEM
APX13	1.0 : STRUCTURES
APX141	1.0 : CASE
APX142	1.0 : INSULATION
APX143	1.0 : LINER
APX144	1.0 : PROPELLENT
APX145	1.0 : NOZZLE
APX146	1.0 : TVC/TVA
APX147	1.0 : IGNITION SYSTEM
APX148	1.0 : PRESHIP ASSEMBLY & CHECKOUT
APX149	1.0 : ADDITIONAL MOTOR LEVEL ITEMS
APX15	1.0 : FLIGHT RECOVERY
APX16	1.0 : SHIPPING AND LOGISTICS
APX17	1.0 : BOOSTER PROGRAM SUPPORT
APX18	1.0 : ADDITIONAL BOOSTER LEVEL ITEMS
APX19	1.0 : SYSTEM SUPPORT
APX21	1.0 : RANGE OPERATIONS
APX22	1.0 : FACTORY SUPPORT RANGE OPERATIONS
APX23	1.0 : RANGE SPARES
APX24	1.0 : FACILITIES AND GROUND SUPPORT
APX32	1.0 : RECOVERY LAND VEHICLES & EQUIPMENT
APX33	1.0 : RECOVERY SEA VEHICLES & EQUIPMENT
APX5	1.0 : RDTE COMPLEXITY FACTOR

BWT — NUMBER OF WEIGHT ATTRIBUTES. VARIABLE BWT IS A DIMENSIONING VALUE FOR VECTOR VARIABLE BXWEIGHT(BWT). BWT KEEPS COUNT OF THE NUMBER OF WEIGHT ATTRIBUTES NEEDED TO RUN STACEM. THE CURRENT CERS REQUIRE DATA ON TWELVE (12) DIFFERENT WEIGHT ATTRIBUTES. WHEN A NEW ATTRIBUTE IS ADDED TO, OR SUBTRACTED FROM BXWEIGHT THE ANALYST MUST UPDATE BWT. SEE BXWEIGHT FOR A LISTING OF THE WEIGHT ATTRIBUTES. (INDEPENDENT, SCALAR)

BWT = 12

BXWEIGHT(BWT) — BOOSTER COMPONENT WEIGHTS IN LBS. BXWEIGHT(BWT) CONTAINS COMPONENT WEIGHTS OF THE SRB FOR STACEM. THE ANALYST MUST INPUT THE WEIGHT, IN POUNDS, FOR THE FOLLOWING SRB COMPONENTS;

1- ELECTRICAL & INSTRUMENTATION WEIGHT
2- SEPARATION SYSTEMS WEIGHT
3- STRUCTURES WEIGHT
4- FLIGHT RECOVERY WEIGHT
5- IGNITION WEIGHT - INCLUDES IGNITION PYROGEN, IF APPLICABLE

VARIABLE NAME	DESCRIPTION/VALUE.....
BXWEIGHT(BWT)	6- LINER WEIGHT 7- NOZZLE WEIGHT - INCLUDES ABLATION MATERIAL, NOZZLE INTERFACE (FLEX-SEAL, BALL-SOCKET, ETC.) 8- PROPELLANT WEIGHT 9- TVC/TVA WEIGHT - FOR LITVC USE INERT WEIGHT 10- INSULATION WEIGHT 11- CASE WEIGHT 12- BOOSTER RECOVERY (INERT) WEIGHT (INDEPENDENT, VECTOR) 0 :W=1 ELECTRICAL & INSTRUMENTATION 0 :W=2 SEPARATION SYSTEM 0 :W=3 STRUCTURES 0 :W=4 FLT.RECOVERY 0 :W=5 IGNITION 0 :W=6 LINER 0 :W=7 NOZZLE 0 :W=8 PROPELLENT 0 :W=9 TVC/TVA 0 :W=10 INSULATION 0 :W=11 CASE 0 :W=12 BOOSTER INERT
BXWT1M(1)	TOTAL WEIGHT OF THE MOTOR. THE VARIABLE BXWT1M CALCULATES THE WEIGHT OF THE SRM. THE VALUE OF THIS VARIABLE IS THE NUMERIC SUM BXWEIGHT(BWT) OF ELEMENTS 5 THROUGH 11. (DEPENDENT, VECTOR) = BXWEIGHT(L); L = 5, 11 :TOTAL MOTOR
BXWT2B(1)	TOTAL WEIGHT OF THE BOOSTER. THE VARIABLE BXWT2B CALCULATES THE WEIGHT OF THE SRB. THE VALUE OF THIS VARIABLE IS THE NUMERIC SUM BXWEIGHT(BWT) OF ELEMENTS 1 THROUGH 11. (DEPENDENT, VECTOR) = BXWEIGHT(M); M = 1, 11 :TOTAL BOOSTER
BY	BASE YEAR OF THE LIFE CYCLE BEGINNING YEAR 1. THIS VARIABLE CONTAINS THE INTEGER NUMBER OF THE BASE REPORTING PERIOD FOR THE Y VARIABLE. BY IS USED TO TEMPORARILY "SET" THE PROGRAM TO BEGIN THE LIFE CYCLE OF THE SRB PROGRAM AT THE YEAR IN WHICH ACTIVITY BEGINS, WHICH CAN BE ANY CALENDAR YEAR. THE PROGRAM IS HARD-SET FROM YEAR 1987. THEREFORE, IF THE PROGRAM BEGINS IN 1987, BY IS 1; HOWEVER, IF THE PROGRAM BEGINS IN 1990, BY IS 3.

VARIABLE NAME DESCRIPTION/VALUE.....

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(INDEPENDENT, SCALAR)
1:BASE YEAR OF THE LIFE CYCLE BEGINNING YEAR 1

CO RATE/SCHEDULE ROWS LABELS. CO IS A DIMENSIONING VARIABLE FOR C1QTY. CO CONTAINS THE VALUE REPRESENTING THE NUMBER OF LIFE CYCLE PHASES THE SCHEDULING CHART WILL CONTAIN DATA FOR: 1 DDT&E, 2 SRB PRODUCTION, 3 LAUNCH SUPPORT, 4 POST-LAUNCH RECOVERY SYSTEM, 5 REFURBISHMENT SYSTEM. (DEPENDENT, SCALAR)

C1QTY(CO,30) ----------RATE SCHEDULE CHART.-----------
C1QTY(CO,30) IS A 5 BY 30 MATRIX WHICH STORES SCHEDULING DATA FOR THE MODEL FOR UP TO 30 YEARS. EACH ROW IN THE MATRIX REPRESENTS ONE OF FIVE PHASES. EACH COLUMN IN THE MATRIX

C1QTY(CO,30) REPRESENTS A PERIOD. THE ANALYST INPUTS THE FOLLOWING DATA INTO C1QTY:
THE FIRST ROW, PHASE 1, IS DDT&E. THE DATA ENTERED REPRESENT THE PERCENTAGE DISTRIBUTION OF DDT&E FUNDING OVER THE LIFE SPAN OF THE SRB PROGRAM. THUS, EACH COLUMN CONTAINS THE PERCENT OF DDT&E FUNDING SPENT FOR THAT PERIOD. WITHIN THE DDT&E PHASE ROW, ALL THE COLUMNS MUST SUM TO 1.0. THE SECOND ROW, PHASE 2, IS SRB PRODUCTION. EACH COLUMN IN THE ROW CONTAINS THE NUMBER OF BOOSTERS PRODUCED FOR THAT PERIOD. SIMILARLY, THE THIRD ROW, PHASE 3, AND THE FIFTH ROW, PHASE 5, CONTAIN THE NUMBER OF BOOSTERS LAUNCHED AND REFURBISHED FOR EACH PERIOD, RESPECTIVELY. THE FOURTH ROW, PHASE 4, CONTAINS THE NUMBER OF RECOVERY OPERATIONS PERFORMED FOR EACH PERIOD.
THE CURRENT VERSION OF C1QTY CONTAINS 30 COLUMNS. THIS ALLOWS THE ANALYST TO DEVELOP LCC ESTIMATES FOR A PROGRAM THAT LASTS UP TO 30 YEARS.

```
FY87 FY88 FY89 FY90 FY91 FY92 FY93 FY94 FY95
.7 .3  0  0  0  0  0  0  0  0  20*0:RDTE
0  1   1  1  1  1  0  0  0  0  20*0:PRDT
0  0   1  1  1  1  1  1  1  0  20*0:LAUN
0  0   1  1  1  1  1  1  1  0  20*0:RECO
0  0   1  0  0  1  0  0  1  0  20*0:REFU
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C2TPRD(1) TOTAL NUMBER OF BOOSTERS PRODUCED. C2TPRD CALCULATES (FROM THE SECOND ROW OF C1QTY) THE TOTAL NUMBER OF BOOSTERS PRODUCED DURING THE

VARIABLE NAME	DESCRIPTION/VALUE.....
C2TPRD (1)	SRB PROGRAM'S LIFE CYCLE. (DEPENDENT, SCALAR)
	=C1QTY(2,I);I=1,Y
C3YPRDB	FIRST YEAR OF BOOSTER PRODUCTION. C3YPRDB CALCULATES (FROM THE SECOND ROW OF C1QTY) THE FIRST YEAR OF BOOSTER PRODUCTION DURING THE SRB PROGRAM'S LIFE CYCLE. (DEPENDENT, SCALAR)
	=GETFIRST(2,C1QTY)
C3YPRDE	LAST YEAR OF BOOSTER PRODUCTION. C3YPRDE CALCULATES (FROM THE SECOND ROW OF C1QTY) THE LAST YEAR OF BOOSTER PRODUCTION DURING THE SRB PROGRAM'S LIFE CYCLE. (DEPENDENT, SCALAR)
	=GETLAST(2,C1QTY)
C3YRDB	FIRST YEAR OF DDT&E. C3YRDB CALCULATES (FROM THE FIRST ROW OF C1QTY) THE FIRST YEAR OF DDT&E DURING THE SRB PROGRAM'S LIFE CYCLE. (DEPENDENT, SCALAR)
	=GETFIRST(1,C1QTY)
C3YRDE	LAST YEAR OF DDT&E. C3YRDE CALCULATES (FROM THE FIRST ROW OF C1QTY) THE LAST YEAR OF DDT&E DURING THE SRB PROGRAM'S LIFE CYCLE. (DEPENDENT, SCALAR)
	=GETLAST(1,C1QTY)
C4RDYS	NUMBER OF PERIODS FOR DDT&E IN YEARS. C4RDYS CALCULATES THE NUMBER OF YEARS IN WHICH THERE ARE DDT&E ACTIVITY. (DEPENDENT, SCALAR)
	=C3YRDE-C3YRDB+1
JXO	DUMMY VARIABLE -- CER MODIFIER. JXO HAS NO SPECIFIED PURPOSE OTHER THAN TO ALLOW THE ANALYST TO MAKE A GLOBAL FACTOR CHANGE IN THE ENTIRE SRB LIFE CYCLE COST ESTIMATION. (INDEPENDENT, SCALAR)
	= 1:DUMMY VARIABLE - GLOBAL
JXAT	AVERAGE THRUST BOOSTER PERFORMANCE SPECIFICATION. JXAT CONTAINS AVERAGE THRUST OF THE SRB. AVERAGE THRUST IS MEASURED IN POUND FORCE (LBF) AT SEA LEVEL AND 100 F. THE

VARIABLE NAME	DESCRIPTION/VALUE.....
JXAT	APPLICABLE RANGE IS FROM 10,000 LBF TO 4,000,000 LBF. (INDEPENDENT, SCALAR) = 0:AVERAGE THRUST
JXCX	SUBJECTIVE LAUNCH COMPLEXITY INDEX. JXCX CONTAINS A SUBJECTIVE COMPLEXITY RATING OF THE BOOST LAUNCH OPERATION. THE APPLICABLE RANGE IS FROM 1 TO 100. EXAMPLES OF RATING IS 95 FOR THE SPACE SHUTTLE, 60 FOR THE PEACEKEEPER, AND 20 FOR ALGOL. (INDEPENDENT, SCALAR) 0 :SUBJECTIVE LAUNCH COMPLEXITY INDEX
JXD2	REUSABLE/EXPENDABLE BOOSTER DISTINGUISHES BETWEEN EXPENDABLE BOOSTERS AND USABLE BOOSTERS. IF THE SRB IS EXPENDABLE, THE VARIABLE HAS A VALUE OF 1. IF THE SRB IS
JXD2	REUSABLE, THE VARIABLE HAS A HAS A VALUE OF 2. (INDEPENDENT, SCALAR) 1 :2-REUSABLE, 1-EXPENDABLE BOOSTER
JXD3	THRUST VECTOR CONTROL/THRUST VECTOR ACTUATOR. JXD3 DISTINGUISHES BETWEEN SRB THRUST VECTORING OPTIONS. IF THE SRB HAS NO THRUST VECTORING CONTROL, THE VARIABLE HAS A VALUE OF 0. IF THE SRB HAS TVC (AND A FIXED NOZZLE) THE VARIABLE HAS A VALUE OF 1. IF THE SRB HAS TVA (AND A MOVABLE NOZZLE), THE VARIABLE HAS A VALUE OF 2. (INDEPENDENT, SCALAR) 0 :2-TVA, 1-TVC, 0-NO THRUST VECTORING
JXNM	MOVABLE/FIXED NOZZLE. JXNM DISTINGUISH BETWEEN FIXED AND MOVABLE NOZZLES. IF THE SRB HAS A FIXED NOZZLE, THE VARIABLE HAS A VALUE OF 1. IF THE SRB HAS A MOVABLE NOZZLE, THE VARIABLE HAS A VALUE OF 2 (MOVABLE NOZZLES ARE NORMALLY IDENTIFIED WITH TVA). (INDEPENDENT, SCALAR) 0 :2-TVA, 1-TVC, 0-NO THRUST VECTORING NOZZLE
JXPD	PROPELLENT DENSITY. JXPD CONTAINS THE PROPELLENT DENSITY. PROPELLENT DENSITY IS MEASURED IN POUNDS PER CUBIC INCHES (LBS/IN3). THE APPLICABLE RANGE IS FROM .06 TO .07 LBS/IN3. (INDEPENDENT, SCALAR)

VARIABLE NAME	DESCRIPTION/VALUE.....
JXPD	0 :PROPELLENT DENSITY
JXTI	TOTAL IMPULSE BOOSTER PERFORMANCE SPECIFICATION. JXTI CONTAINS TOTAL IMPULSE OF THE SRB. TOTAL IMPULSE IS MEASURED IN POUNDS FORCE PER SECONDS (LBF-SEC). THE APPLICABLE RANGE IS FROM 100,000 LBF-SEC TO 350,000,000 LBF-SEC. (INDEPENDENT, SCALAR)
	0 :TOTAL IMPULSE (LBF-SEC)
JXVO	CASE VOLUME. JXVO CONTAINS THE CASE VOLUME OF THE SRB. CASE VOLUME INCLUDES TOTAL DISPLACEMENT VOLUME OF CASE INCLUDING AFT AND FORWARD DOME. CASE VOLUME IS MEASURED IN CUBIC VOLUME (CFT). THE APPLICABLE RANGE IS FROM 15 CFT TO 20,000 CFT. (INDEPENDENT, SCALAR)
JXVO	0 :CASE VOLUME (CFT)
KDISTTR	DISTANCE BETWEEN MFG. FACILITY AND R&D TEST RANGE. KDISTTR CONTAINS THE DISTANCE, IN MILES, BETWEEN THE MANUFACTURING FACILITY AND THE R&D TEST RANGE. (INDEPENDENT, SCALAR)
	0 :DIST BET MFG FAC & R&D TEST RANGE (MILES)
KNGTST	NUMBER OF GROUND TEST MOTORS. KNGTST CONTAINS THE NUMBER OF BOOSTERS OR MOTORS USED IN STATIC GROUND TESTS AND EVALUATION. (INDEPENDENT, SCALAR)
	0 :# GROUND TEST MOTORS
KNLF	NUMBER OF LAUNCH FACILITIES UTILIZED IN THE PROGRAM. KNLF CONTAINS THE NUMBER OF NATIONAL GEOGRAPHIC LOCATIONS WILL BE USED BY THE SRB PROGRAM (NOT THE NUMBER OF LAUNCH PADS). CURRENTLY THERE ARE ONLY TWO LAUNCH FACILITIES ON THE CONTINENTAL USA; THEREFORE, KNLF CAN HAVE A VALUE OF 1 OR 2. (INDEPENDENT, SCALAR)
	0 :# LAUNCH FACILITIES UTILIZED
KNUM1MFT	NUMBER OF R&D FLIGHT TESTS PERFORMED. KNUM1MFT CONTAINS THE ESTIMATED NUMBER OF DDT&E FLIGHT TESTS TO BE PERFORMED THROUGHOUT THE SRB PROGRAM LIFE CYCLE. (INDEPENDENT, SCALAR)

VARIABLE NAME	DESCRIPTION/VALUE.....
KNUMiMFT	0 :# R&D FLIGHT TESTS PERFORMED
KNYFT	NUMBER OF YEARS FOR R&D FLIGHT TEST PHASE. KNYFT CONTAINS THE NUMBER OF YEARS THE R&D FLIGHT TESTING PHASE OF THE SRB PROGRAM LIFE CYCLE WILL LAST. (INDEPENDENT, SCALAR) 0 :# YEARS FOR R&D FLIGHT TEST PHASE
KPPLT	PERCENT OF PROPELLENT LOADING PER R&D TEST. KPPLT CONTAINS THE PERCENTAGE OF PROPELLENT LOADED IN TEST MOTOR FOR R&D TEST AND EVALUATION. (INDEPENDENT, SCALAR) 0 :% PROPELLENT LOADING PER R&D TEST
KRDFAC	ESTIMATED COST OF DDT&E & PRODUCTION FACILITIES. KRDFAC CONTAINS THE ESTIMATED
KRDFAC	COST, IN FY 87 DOLLARS, FOR THE DDT&E AND PRODUCTION FACILITIES. (INDEPENDENT, SCALAR) 0 :COST OF RDT&E FACILITIES (FY 87 $)
KUNBS	NUMBER OF BOOSTERS USED PER LAUNCH. KUNBS CONTAINS THE NUMBER OF BOOSTERS USED PER LAUNCH, I.E THE CONFIGURATION OF THE STRAPPED ON BOOSTERS. (INDEPENDENT, SCALAR) 0 :# OF BOOSTERS USED PER LAUNCH
L1LCF(4)	LEARNING CURVE FACTOR (PERCENT). L1LCF CONTAINS THE CUMULATIVE AVERAGE LEARNING CURVE FACTORS FOR EACH PHASE OF THE SRB LIFE CYCLE. THERE ARE FOUR PHASES WHERE LEARNING CURVES ARE APPLICABLE; PRODUCTION, LAUNCH SUPPORT, RECOVERY, AND REFURBISHMENT PHASES. THE DDT&E PHASE ACTIVITIES ARE NOT AFFECTED BY LEARNING CURVE EFFECTS. THE EXACT LEARNING CURVE FACTOR MAY VARY FROM PHASE TO PHASE. 0 :PRODUCTION
L2LCK(J)	LEARNING CURVE CONSTANT. L2LCK CALCULATES THE LEARNING CURVE CONSTANT MATRIX. FACTOR J IS CALCULATED FROM THE LEARNING CURVE FACTOR L1LCF(4). (DEPENDENT, MATRIX) =(LOG10(L1LCF(J)/100))/(LOG10(2));J=1,4

VARIABLE NAME	DESCRIPTION/VALUE.....
L3UNL(A,K)	MATRIX DEVELOPER. L3UNL DEVELOPS A 4X4 MATRIX TO BE USED IN OTHER VARIABLES. (DEPENDENT, MATRIX) =0;A=1,4, K=1,Y
L3UNL(C,I)	LAST UNIT NUMBER IN C1QTY MATRIX. L3UNL CALCULATES THE PERIOD IN WHICH THE LAST UNIT IS COMPLETED IN THE SECOND, THIRD, FOURTH, AND FIFTH PHASES OF THE SRB PROGRAM BEING COSTED. (DEPENDENT, MATRIX) = L3UNL(C,I-1)+C1QTY(C+1,I);C=1,4, I=1,Y
L4UNF(C,I)	FIRST UNIT NUMBER IN C1QTY MATRIX. L4UNF CALCULATES THE PERIOD IN WHICH THE FIRST UNIT IS COMPLETED IN THE SECOND, THIRD, FOURTH, AND FIFTH PHASES OF THE SRB PROGRAM BEING COSTED. (DEPENDENT, MATRIX)
L4UNF(C,1)	=L3UNL(C,I)-(C1QTY(C+1,I) -1*(.GE.(C1QTY(C+1,I),1))); C=1,4, I=1,Y
L5UNA(C,I)	AVERAGE LEARNING CURVE FACTOR FOR A PERIOD. L4UNA CALCULATES THE MULTIPLICATIVE LEARNING CURVE FACTORS AND THEN STORES THESE VALUES. (DEPENDENT, MATRIX) =((L3UNL(C,I)+L4UNF(C,I))/2)**L2LCK(C); C=1,4, I=1,Y
M1CSTCAP	COST OF CAPITALIZATION. M1CSTCAP CONTAINS THE ANNUAL COMBINED PERCENTAGE COST OF CAPITAL ADDING THE DOMINANT INTEREST RATE WITH A STRAIGHT LINE DEPRECIATION PERCENTAGE. THE VALUE IMPUTED SHOULD BE A PERCENTAGE. (INDEPENDENT, SCALAR) 0 :COST OF CAPITALIZATION (PERCENT)
M1MF	MANNING FACTOR. M1MF IS USED TO DISTINGUISH BETWEEN UNMANNED OR MANNED SYSTEMS. THIS VARIABLE IS USED IN THE LAUNCH SUPPORT PHASE OF THE MODEL AS AN ADJUSTMENT FACTOR FOR THE COST DIFFERENCES IN MANNED AND UNMANNED SYSTEMS. IF THE FLIGHT IS UNMANNED, THE VARIABLE HAS THE VALUE OF 1. IF THE FLIGHT IS MANNED, THE VARIABLE HAS A VALUE OF 2. (INDEPENDENT, SCALAR) 1 :1-UNMANNED, 2-MANNED

VARIABLE NAME	DESCRIPTION/VALUE.....
Y	PROGRAM LIFE CYCLE TIME. Y CALCULATES, FROM YEARS, THE LAST YEAR IN WHICH THERE IS ACTIVITY FOR THE SRB PROGRAM BEING COSTED. (DEPENDENT, SCALAR) =GETMAX(1,YEARS)
YEARS(1,CO)	YEARS. YEARS CALCULATES THE LAST YEAR OF ACTIVITY FOR EACH OF THE FIVE PHASES. (DEPENDENT, MATRIX) C3YRDE,C3YRSE,C3YPRDE,C3YLSE,C3YPRSE
YX	NUMBER OF PHASES. YX IS A SCALAR VARIABLE WHICH CONTAINS THE NUMBER OF PHASES OF THE SRB PROGRAM BEING COSTED. (DEPENDENT, SCALAR) = 5
YXGA(YX)	GENERAL AND ADMINISTRATIVE CHARGES. YXGA CONTAINS THE PERCENTAGE OF TOTAL PHASE EXPENDITURES WHICH ARE G&A CHARGES ASSOCIATED WITH EACH OF THE FIVE PHASES OF THE SRB LIFE CYCLE. (INDEPENDENT, VECTOR) 0 :PRODUCTION 0 :DDT&E
YZFE(YX)	FEE CHARGES. YZFE CONTAINS THE PERCENTAGE OF TOTAL PHASE EXPENDITURES WHICH ARE FEES ASSOCIATED WITH EACH OF THE FIVE PHASES OF THE SRB LIFE CYCLE. (INDEPENDENT, VECTOR) 0 :PRODUCTION 0 :DDT&E
Z1.1(1)	ELECTRICAL & INSTRUMENTATION. Z1.1 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF E&I FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(3205)*(BXWEIGHT(1))
Z1.2(1)	SEPARATION SYSTEM. Z1.2 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF SEPARATION SYSTEM FOR A COMPLETE, MANUFACTURED FIRST UNIT (DEPENDENT, VECTOR) =(1771)*(BXWEIGHT(2))

VARIABLE NAME	DESCRIPTION/VALUE.....
Z1.3(1)	STRUCTURES. Z1.3 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF STRUCTURE FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(.EQ.(JXD2,1)*(114*BXWEIGHT(3))) +(.EQ.(JXD2,2)*(359*BXWEIGHT(3)))
Z1.4.1(1)	CASE. Z1.4.1 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF THE CASE FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =((-291291+(330.86*JXVO)+(382584*JXD2)) *(-539179+(50.57*BXWEIGHT(11)) +(737152*JXD2)))**.5
Z1.4.2(1)	INSULATION. Z1.4.2 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF THE INSULATION FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(17644+23.2303*JXVO)+(9.6978*BXWEIGHT(10))
Z1.4.3(1)	LINER. Z1.4.3 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF THE LINER FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(873.776*(BXWEIGHT(6)**.2514))
Z1.4.4(1)	PROPELLANT. Z1.4.4 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF THE PROPELLANT FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(158703+45.1566*(BXWEIGHT(8))/(JXPD*1728)) +(1.5249*(BXWEIGHT(8)))
Z1.4.5(1)	NOZZLE. Z1.4.5 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF THE NOZZLE FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =((.EQ.(JXNM,2))*(.5*(325250+108*BXWEIGHT(7)) +.5*(273250+.97*JXAT)))+((.EQ.(JXNM,1)) *(.5*(85005+131*BXWEIGHT(7))+.5*(57701+1.03 *JXAT)))+((.EQ.(JXNM,0)) *(.5*(45053+69.4*BXWEIGHT(7)) +.5*(30582+.54*JXAT)))
Z1.4.6(1)	THRUST VECTOR CONTROL. Z1.4.6 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF TVC

VARIABLE NAME	DESCRIPTION/VALUE.....
Z1.4.6(1)	COMPONENTS FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(10821.812)*(BXWEIGHT(9)**.5454) *(JXD3**1.4377)*(.GE.(JXD3,.5))
Z1.4.7(1)	IGNITION SYSTEM. Z1.4.7 CALCULATES THE COST ESTIMATE IN FY87 DOLLARS OF THE IGNITION SYSTEM FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(5799+(189.2*BXWEIGHT(5)))
Z1.4.8(1)	PRE-SHIP ASSEMBLY & CHECKOUT. Z1.4.8 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS OF THE PRE-SHIP ASSEMBLY AND CHECKOUT
Z1.4.8(1)	COMPONENTS FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =.9359*(BXWT1M(1))
Z1.4.9(1)	ADDITIONAL MOTOR LEVEL ITEMS (SPECIFY). Z1.4.9 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS OF THE ADDITIONAL MOTOR LEVEL ITEMS FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(.0215)*(685809+(.127*JXTI))
Z1.5(1)	FLIGHT RECOVERY EQUIPMENT. Z1.5 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS OF THE FLIGHT RECOVERY EQUIPMENT FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(398.07)*(BXWEIGHT(4)**.9)
Z1.6(1)	SHIPPING AND LOGISTICS. Z1.6 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS OF THE SHIPPING AND LOGISTICS FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =67.9516*(BXWT1M(1)**.4922)*(.EQ.(KNLF,1)*.431 +.EQ.(KNLF,2))
Z1.7(1)	BOOSTER PROGRAM SUPPORT. Z1.7 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS OF THE BOOSTER PROGRAM SUPPORT FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =.15*(Z1.4.1(1)+Z1.4.2(1)+Z1.4.3(1)+Z1.4.4(1)

VARIABLE NAME DESCRIPTION/VALUE.....

Z1.7(1)	+Z1.4.5(1)+Z1.4.6(1)+Z1.4.7(1)+Z1.4.8(1) +Z1.4.9(1)+Z1.5(1)+Z1.6(1))
Z1.8(1)	ADDITIONAL BOOSTER LEVEL ITEMS. Z1.8 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF THE ADDITIONAL BOOSTER LEVEL ITEMS FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =(120492+(1.31*BXWT2B(1)))
Z1.9(1)	OVERALL SYSTEMS SUPPORT. Z1.9 CALCULATES THE COST ESTIMATE, IN FY87 DOLLARS, OF THE OVERALL SYSTEMS SUPPORT FOR A COMPLETE, MANUFACTURED FIRST UNIT. (DEPENDENT, VECTOR) =.11*(Z1.4.1(1)+Z1.4.2(1)+Z1.4.3(1)+Z1.4.4(1) +Z1.4.5(1)+Z1.4.6(1)+Z1.4.7(1)+Z1.4.8(1) +Z1.4.9(1)+Z1.5(1)+Z1.6(1))

Appendix B

STACEM Cost Estimating Relationships

CES NUMBER	REC TYPE	CONT	DESCRIPTION/VALUE....
0	CS	1	ROCKET LIFE CYCLE COST
1.	CS	1	SOLID ROCKET BOOSTER
1.01	CS	1	.ELECTRICAL & INSTRUMENTATION
1.01	EQ	1	APX11*Z1.1(1)*JXO
1.01	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.02	CS	1	.SEPARATION SYSTEM
1.02	EQ	1	APX12*Z1.2(1)*JXO
1.02	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.03	CS	1	.STRUCTURES
1.03	EQ	1	APX13*Z1.3(1)*JXO
1.03	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04	CS	1	.SOLID ROCKET MOTOR
1.04.1	CS	1	..CASE
1.04.1	EQ	1	APX141*Z1.4.1(1)*JXO
1.04.1	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.2	CS	1	..INSULATION
1.04.2	EQ	1	APX142*Z1.4.2(1)*JXO
1.04.2	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.3	CS	1	..LINER
1.04.3	EQ	1	APX143*Z1.4.3(1)*JXO
1.04.3	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.4	CS	1	..SOLID FUEL
1.04.4	EQ	1	APX144*Z1.4.4(1)*JXO
1.04.4	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.5	CS	1	..NOZZLE
1.04.5	EQ	1	APX145*Z1.4.5(1)*JXO
1.04.5	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.6	CS	1	..THRUST VECTOR CONTROL
1.04.6	EQ	1	APX146*Z1.4.6(1)*JXO
1.04.6	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.7	CS	1	..IGNITION SYSTEM
1.04.7	EQ	1	APX147*Z1.4.7(1)*JXO
1.04.7	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.8	CS	1	..PRESHIP-ASSEMBLY & CHECKOUT
1.04.8	EQ	1	APX148*Z1.4.8(1)*JXO
1.04.8	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.04.9	CS	1	..ADDITIONAL MOTOR-LEVEL ITEMS (SPECIFY
1.04.9	EQ	1	APX149*Z1.4.9(1)*JXO
1.04.9	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.05	CS	1	.FLIGHT RECOVERY EQUIPMENT
1.05	EQ	1	APX15*Z1.5(1)*JXO
1.05	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.06	CS	1	.SHIPPING AND LOGISTICS
1.06	EQ	1	APX16*Z1.6(1)*JXO

CES NUMBER	REC TYPE	CONT	DESCRIPTION/VALUE....
1.06	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.07	CS	1	.BOOSTER PROGRAM SUPPORT
1.07	EQ	1	APX17*Z1.7(1)*JXO
1.07	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.08	CS	1	.ADDITIONAL BOOSTER-LEVEL ITEMS
1.08	EQ	1	APX18*Z1.8(1)*JXO
1.08	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.09	CS	1	.OVERALL SYSTEMS SUPPORT
1.09	EQ	1	APX19*Z1.9(1)*JXO
1.09	EQ	2	*C1QTY(2,I)*L5UNA(1,I);I=C3YPRDB,C3YPRDE
1.10	CS	1	.ADDITIONAL G&A AND FEES
1.10.1	CS	1	..GENERAL & ADMINISTRATIVE
1.10.1	EQ	1	($1.01+$1.02+$1.03+$1.04.1+$1.04.2
1.10.1	EQ	2	+$1.04.3+$1.04.4+$1.04.5+$1.04.6
1.10.1	EQ	3	+$1.04.7+$1.04.8+$1.04.9+$1.05+$1.06
1.10.1	EQ	4	+$1.07+$1.08+$1.09)*(YXGA(1)/100);
1.10.1	EQ	5	I=C3YPRDB,C3YPRDE
1.10.2	CS	1	..FEES
1.10.2	EQ	1	($1.01+$1.02+$1.03+$1.04.1+$1.04.2
1.10.2	EQ	2	+$1.04.3+$1.04.4+$1.04.5+$1.04.6
1.10.2	EQ	3	+$1.04.7+$1.04.8+$1.04.9+$1.05+$1.06
1.10.2	EQ	4	+$1.07+$1.08+$1.09+$1.10.1)
1.10.2	EQ	5	*(YXGA(1)/100); I=C3YPRDB,C3YPRDE
5.	CS	1	DDT&E (A)
5.01	CS	1	.STAGE ENGINEERING
5.01	EQ	1	APX5*JXO*(5570000*BXWEIGHT(3)
5.01	EQ	2	**.118+KRECDDTE)*C1QTY(1,I);
5.01	EQ	3	I=C3YRDB,C3YRDE
5.02	CS	1	.PROPULSION
5.02	EQ	1	APX5*JXO*(((.LE.(JXD3,2))
5.02	EQ	2	+1.28*(.EQ.(JXD3,2)))
5.02	EQ	3	*261000*BXWT1M(1)**.41)
5.02	EQ	4	*C1QTY(1,I);I=C3YRDB,C3YRDE
5.03	CS	1	.TRAINING
5.03	EQ	1	APX5*JXO*(50600*(MAX(10,C4RDYS)))
5.03	EQ	2	*C1QTY(1,I);I=C3YRDB,C3YRDE
5.04	CS	1	.TEST HARDWARE
5.04	EQ	1	APX5*JXO*(KNGTST*(Z1.4.1(1)
5.04	EQ	2	+Z1.4.2(1)+Z1.4.3(1)
5.04	EQ	3	+(Z1.4.4(1)*(KPPLT/100))+Z1.4.5(1)
5.04	EQ	4	+Z1.4.7(1)+.07*KDISTTR*BXWT1M(1)
5.04	EQ	5	*1.25/2000))*C1QTY(1,I);I=C3YRDB,C3YRDE
5.05	CS	1	.TEST OPERATIONS
5.05	EQ	1	APX5*JXO*(KNGTST*750000+880000*KNUM1MFT
5.05	EQ	2	+5850000*KNYFT*(MIN(JXD2,1.5)))
5.05	EQ	3	*C1QTY(1,I);I=C3YRDB,C3YRDE
5.06	CS	1	.FACILITIES
5.06	EQ	1	APX5*JXO*((KRDFAC)/C4RDYS)
5.06	EQ	2	*.GE.(C1QTY(1,I),0) ;I=C3YRDB,C3YRDE

CES NUMBER	REC TYPE	CONT	DESCRIPTION/VALUE....
5.07	CS	1	.GROUND SUPPORT EQUIPMENT
5.07	EQ	1	APX5*JX0*(.04*($5.01+$5.02))
5.07	EQ	2	;I=C3YRDB,C3YRDE
5.08	CS	1	.SYSTEM INTEGRATION
5.08	EQ	1	APX5*JX0*(.04*($5.01+$5.02+$5.03
5.08	EQ	2	+$5.04+$5.05+$5.06+$5.07))
5.08	EQ	3	;I=C3YRDB,C3YRDE
5.09	CS	1	.TOOLING
5.09	EQ	1	APX5*JX0*(.0445*(Z1.4.1(1)+Z1.4.2(1)
5.09	EQ	2	+Z1.4.3(1)+Z1.4.4(1)+Z1.4.5(1)+Z1.4.6(1)
5.09	EQ	3	+Z1.4.7(1)+Z1.4.8(1)+Z1.4.9(1)))
5.09	EQ	4	;I=C3YPRDB,C3YPRDE
5.10	CS	1	.ADDITIONAL G&A AND FEES
5.10.1	CS	1	..GENERAL & ADMINISTRATIVE
5.10.1	EQ	1	($5.01+$5.02+$5.03+$5.04+$5.05+$5.06
5.10.1	EQ	2	+$5.07+$5.08+$5.09)*(YXGA(5)/100);
5.10.1	EQ	3	I=C3YPRDB,C3YPRDE
5.10.2	CS	1	..FEES
5.10.2	EQ	1	($5.01+$5.02+$5.03+$5.04+$5.05+$5.06
5.10.2	EQ	2	+$5.07+$5.08+$5.09+$5.10.1)
5.10.2	EQ	3	*(YZFE(5)/100);
5.10.2	EQ	4	I=C3YPRDB,C3YPRDE

Appendix C
STACEM Variable Values

AFIT Engineering
STACEM Input Variables for Second Stage Booster

Variable	Value : Description
APX11	.60 : ELECTRICAL & INSTRUMENTATION
APX12	.60 : SEPARATION SYSTEM
APX13	.60 : STRUCTURES
APX141	.90 : CASE
APX142	.90 : INSULATION
APX143	.90 : LINER
APX144	1.0 : PROPELLENT
APX145	.90 : NOZZLE
APX146	1.0 : TVC/TVA
APX147	.60 : IGNITION SYSTEM
APX148	.60 : PRESHIP ASSEMBLY & CHECKOUT
APX149	.60 : ADDITIONAL MOTOR LEVEL ITEMS
APX15	1.0 : FLIGHT RECOVERY
APX16	.60 : SHIPPING AND LOGISTICS
APX17	.60 : BOOSTER PROGRAM SUPPORT
APX18	.60 : ADDITIONAL BOOSTER LEVEL ITEMS
APX19	.60 : SYSTEM SUPPORT
APX21	.60 : RANGE OPERATIONS
APX22	.60 : FACTORY SUPPORT RANGE OPERATIONS
APX23	.60 : RANGE SPARES
APX24	.60 : FACILITIES AND GROUND SUPPORT
APX32	.60 : RECOVERY LAND VEHICLES & EQUIPMENT
APX33	.60 : RECOVERY SEA VEHICLES & EQUIPMENT
APX5	.60 : RDTE COMPLEXITY FACTOR
BXWEIGHT(BWT)	BOOSTER COMPONENT WEIGHTS IN LBS
	40 : W=1 ELECTRIC
	15 : W=2 SEPARATION SYSTEM
	308 : W=3 STRUCTURES
	0 : W=4 FLT.RECOVERY
	20 : W=5 IGNITION
	25 : W=6 LINER
	423 : W=7 NOZZLE
	23500:W=8 PROPELLENT
	15 : W=9 TVC/TVA
	241 : W=10 INSULATION
	274 : W=11 CASE
	0 : W=12 BOOSTER INERT
BY	6 : BASE YEAR OF THE LIFE CYCLE

Variable	Value : Description
C1QTY(C0,30)	----------RATE SCHEDULE CHART.-----------
	FY87 FY88 FY89 FY90 FY91 FY92 FY93 FY94 FY95
	7*0 .3 .2 .2 .1 .1 .1 17*0 :RDTE
	13*0 11*60 1*14 5*0:PRDT
JX0	1 : DUMMY VARIABLE - GLOBAL
JXAT	75000: AVERAGE THRUST
JXCX	50 : SUBJECTIVE LAUNCH COMPLEXITY INDEX
JXD2	1 : 2-REUSABLE, 1-EXPENDABLE BOOSTER
JXD3	1 : 2-TVA, 1-TVC, 0-NO THRUST VECTORING NOZZLE
JXNM	1 : 2-TVA, 1-TVC, 0-NO THRUST VECTORING NOZZLE
JXPD	.06243264 : PROPELLANT DENSITY (LBS/IN3)
JXTI	6750000 : TOTAL IMPULSE (LBF-SEC)
JXVO	415 : CASE VOLUME (CFT)
KCOPSFAC	0 : COST OF OPERATION FACILITIES (FY 87 $)
KDISTTR	1736 : DIST BET MFG FAC & R&D TEST RANGE (MILES)
KNGTST	21 : # GROUND TEST MOTORS
KNLF	1 : # LAUNCH FACILITIES UTILIZED
KNUM1MFT	30 : # R&D FLIGHT TESTS PERFORMED
KNYFT	3 : # YEARS FOR R&D FLIGHT TEST PHASE
KPPLT	100 : % PROPELLENT LOADING PER R&D TEST
KPRODFAC	0 : COST LAUNCH SUPPORT FAC (FY 87 $)
KRDFAC	34480000 : COST OF RDT&E FACILITIES (FY 87 $)
KRECDDTE	0 : COST OF RECOVERY RDT&E (FY 87 $)
KUNBS	1 : # OF BOOSTERS USED PER LAUNCH
L1LCF(4)	LEARNING CURVE FACTOR (PERCENT)
	95 : PRODUCTION
M1CSTCAP	10 : COST OF CAPITALIZATION (PERCENT)
M1LNDDST	0 : LAND TRANSPORT DIST RECOVERED BOOSTERS (MILES)
M1MANCST	0 : LAND OPS CREW COST/MAN YEAR (FY 87 $)
M1MF	1 : 1-UNMANNED, 2-MANNED
M1RECMOD	0 : 1-SEA RECOVERY, 0-LAND RECOVERY ONLY
M1SHPLFE	0 : USEFUL LIFE OF RECOVERY SHIP (YEARS)
	NUMBER OF TIMES REUSED
N11	0 : ELECTRICAL & INSTRUMENTATION
N13	0 : STRUCTURES
N141	0 : CASE
N145	0 : NOZZLE
N146	0 : TVC
N147	0 : IGNITION
N149	0 : ADDL MOTOR LEVEL ITEMS
N15	0 : FLIGHT RECOVERY EQUIPMENT
YXGA(YX)	GENERAL AND ADMINISTRATIVE CHARGES
	10: PRODUCTION
	20: DDT&E

Variable	Value : Description
YZFE(YX)	FEE CHARGES
	13: PRODUCTION
	13: DDT&E

Phillips Laboratory
STACEM Input Variables for Second Stage Booster

Variable	Value : Description
APX11	.60 : ELECTRICAL & INSTRUMENTATION
APX12	.60 : SEPARATION SYSTEM
APX13	.60 : STRUCTURES
APX141	1.0 : CASE
APX142	1.0 : INSULATION
APX143	1.0 : LINER
APX144	1.0 : PROPELLENT
APX145	1.0 : NOZZLE
APX146	1.0 : TVC/TVA
APX147	1.0 : IGNITION SYSTEM
APX148	1.0 : PRESHIP ASSEMBLY & CHECKOUT
APX149	1.0 : ADDITIONAL MOTOR LEVEL ITEMS
APX15	1.0 : FLIGHT RECOVERY
APX16	.90 : SHIPPING AND LOGISTICS
APX17	.90 : BOOSTER PROGRAM SUPPORT
APX18	1.0 : ADDITIONAL BOOSTER LEVEL ITEMS
APX19	.90 : SYSTEM SUPPORT
APX21	.90 : RANGE OPERATIONS
APX22	1.0 : FACTORY SUPPORT RANGE OPERATIONS
APX23	1.0 : RANGE SPARES
APX24	.90 : FACILITIES AND GROUND SUPPORT
APX32	1.0 : RECOVERY LAND VEHICLES & EQUIPMENT
APX33	1.0 : RECOVERY SEA VEHICLES & EQUIPMENT
APX5	1.0 : RDTE COMPLEXITY FACTOR
BXWEIGHT(BWT)	BOOSTER COMPONENT WEIGHTS IN LBS
	40 : W=1 ELECTRICAL & INSTRUMENTATION
	15 : W=2 SEPARATION SYSTEM
	308 : W=3 STRUCTURES
	0 : W=4 FLT.RECOVERY
	15.3 :W=5 IGNITION
	25 : W=6 LINER
	423 : W=7 NOZZLE
	23126:W=8 PROPELLENT
	14 : W=9 TVC/TVA
	260 : W=10 INSULATION
	112 : W=11 CASE
	0 : W=12 BOOSTER INERT
BY	6:BASE YEAR OF THE LIFE CYCLE
C1QTY(CO,30)	----------RATE SCHEDULE CHART.-----------
	FY87 FY88 FY89 FY90 FY91 FY92 FY93 FY94 FY95
	7*0 .3 .2 .2 .1 .1 .1 17*0 :RDTE
	13*0 11*60 1*14 5*0:PRDT

Variable	Value : Description
JXO	1 : DUMMY VARIABLE - GLOBAL
JXAT	238924:AVERAGE THRUST
JXCX	50 : SUBJECTIVE LAUNCH COMPLEXITY INDEX
JXD2	1 : 2-REUSABLE, 1-EXPENDABLE BOOSTER
JXD3	1 : 2-TVA, 1-TVC, 0-NO THRUST VECTORING NOZZLE
JXNM	1 : 2-TVA, 1-TVC, 0-NO THRUST VECTORING NOZZLE
JXPD	.06243264 : PROPELLANT DENSITY (LBS/IN3)
JXTI	11173699 : TOTAL IMPULSE (LBF-SEC)
JXVO	297 : CASE VOLUME (CFT)
KCOPSFAC	0 : COST OF OPERATION FACILITIES (FY 87 $)
KDISTTR	1736 : DIST BET MFG FAC & R&D TEST RANGE (MILES)
KNGTST	21 : # GROUND TEST MOTORS
KNLF	1 : # LAUNCH FACILITIES UTILIZED
KNUM1MFT	30 : # R&D FLIGHT TESTS PERFORMED
KNYFT	3 : # YEARS FOR R&D FLIGHT TEST PHASE
KPPLT	100 : % PROPELLENT LOADING PER R&D TEST
KPRODFAC	0 : COST LAUNCH SUPPORT FAC (FY 87 $)
KRDFAC	34480000 : COST OF RDT&E FACILITIES (FY 87 $)
KRECDDTE	0 : COST OF RECOVERY RDT&E (FY 87 $)
KUNBS	1 : # OF BOOSTERS USED PER LAUNCH
L1LCF(4)	LEARNING CURVE FACTOR (PERCENT)
	95 : PRODUCTION
M1CSTCAP	10 : COST OF CAPITALIZATION (PERCENT)
M1LNDDST	0 : LAND TRANSPORT DIST RECOVERED BOOSTERS (MILES)
M1MANCST	0 : LAND OPS CREW COST/MAN YEAR (FY 87 $)
M1MF	1 : 1-UNMANNED, 2-MANNED
M1RECMOD	0 : 1-SEA RECOVERY, 0-LAND RECOVERY ONLY
M1SHPLFE	0 : USEFUL LIFE OF RECOVERY SHIP (YEARS)
	NUMBER OF TIMES REUSED
N11	0 : ELECTRICAL & INSTRUMENTATION
N13	0 : STRUCTURES
N141	0 : CASE
N145	0 : NOZZLE
N146	0 : TVC
N147	0 : IGNITION
N149	0 : ADDL MOTOR LEVEL ITEMS
N15	0 : FLIGHT RECOVERY EQUIPMENT
YXGA(YX)	GENERAL AND ADMINISTRATIVE CHARGES
	10 : PRODUCTION
	20 : DDT&E
YZFE(YX)	FEE CHARGES
	13:PRODUCTION
	13:DDT&E

Appendix D
STRAMICE Model

Strategic Missile Cost Estimating (STRAMICE) Model
(reprinted from Table 7-4, AFR 173-13, 2 September 1986)

Cost Element	Algorithm
1. Unit Mission Personnel	
1.1 Operations/Crew	
1.1.1 Military	(F5xF32+F6xF33)
1.1.2 Civilians	(F7xF34)
1.2 Maintenance	
1.2.1 Military	(F8xF32+F9xF33)
1.2.2 Civilian	(F10xF34)
1.3 Munitions	
1.3.1 Military	(F11xF32+F12xF33)
1.3.2 Civilian	(F13xF34)
1.4 Communications	
1.4.1 Military	(F14xF32+F15xF33)
1.4.2 Civilian	(F16xF34)
1.5 Security	
1.5.1 Military	(F17xF32+F18xF33)
1.5.2 Civilian	(F19xF34)
1.6 Other Staff	
1.6.1 Military	(F20xF32+F21xF33)
1.6.2 Civilian	(F22xF34)
2. Unit Level Consumption	
2.1 Fuel POL	(F1xF40)
2.2 Maintenance Materials	(F1xF41)
2.3 Operations Materials	(F1xF42)
3. Depot Maintenance (1)	
3.1 Missile Overhaul	(F1xF80)
3.2 Missile Frame	(F1xF81)
3.3 Propulsion System	(F1xF82)
3.4 Missile Accessories	(F1xF83)
3.5 Support and Launch	(F1xF84)
3.6 Guidance System	(F1xF85)
3.7 Surface Communication & Control	(F1xF86)
3.8 Payload System	(F1xF87)

Cost Element	Algorithm
4. Sustaining Investment	
4.1 Replenishment Spares	(F1xF44)
4.2 Replacement Support Equipment	(F1xF45)
4.3 Class IV Modifications	(F1xF46)
4.4 Software Support	(F1xF47)
5. Other Direct Costs	
5.1 Operational TDY Travel (2)	(F1xF48)
5.2 Sustaining Engineering	(F1xF50)
5.3 Lease	(F1xF51)
5.4 Operational TDY Travel	(F1xF52)
5.5 Second Destination Transportation	(F1xF90)
5.6 Helicopter Support	CORE model
5.7 Other Contract Services	(F1xF53)
6. Installation Support Personnel (3)	
6.1 Base Operating Support	
6.1.1 Military	(F23xF32+F24xF33)
6.1.2 Civilian	(F25xF34)
6.2 Real Property Maintenance	
6.2.1 Military	(F26xF32+F27xF33)
6.2.2 Civilian	(F28xF34)
6.3 Medical	
6.3.1 Military	(F29xF32+F30xF33)
6.3.2 Civilian	(F31xF34)
7. Indirect Personnel Support	
7.1 Installation Support, Non-Pay	(F2+F3+F23+F24+F26 +F27+F29+F30)xF62
7.2 Medical O&M, Non-Pay	
7.2.1 Officer	(F2+F23+F26+F29)xF65
7.2.2 Enlisted	(F3+F24+F27+F30)xF66
7.3 PCS	
7.3.1 Officer	(F2+F23+F26+F29)xF63
7.3.2 Enlisted	(F3+F24+F27+F30)xF64
8. Acquisition and Training	
8.1 Officer Weighted Avg. System Acq. and Trng. Cost (4)	(F2+F23+F26+F29)xF54
8.2 Enlisted Weighted Avg. System Acq. and Trng Cost (4)	(F3+F24+F27+F30)xF55
8.3 CCTS	(F5xF56xF60)

(1) When detail algorithms are not available,

3. Depot maintenance	F1xF43

(2) When operational test launches are a variable under consideration for change,

5.1 Operational test and analysis	F49xF92

(3) When indirect support personnel are not available, estimate SAC support personnel as follows:

F23 = .0028x(F2+F3+F4)
F24 = .1230x(F2+F3+F4)
F25 = .0321x(F2+F3+F4)
F26 = 0
F27 = .0035x(F2+F3+F4+F23+F24+F25)
F28 = .0035x(F2+F3+F4+F23+F24+F25)
F29 = .0024x(F2+F3+F23+F24+F27)
F30 = .0071x(F2+F3+F23+F24+F27)
F31 = .0019x(F2+F3+F23+F24+F27)

(4) When weighted average system acquisition and training cost factors are not available,

8.1 Acquisition	
8.1.1 Officer	(F2+F23+F26+F29)xF60xF67
8.1.2 Enlisted	(F2+F24+F27+F30)xF61xF68
8.2 Specialty Training	
8.2.1 Officer	(F2+F23+F26+F29)xF60xF69
8.2.2 Enlisted	(F3+F24+F27+F30)xF61xF70

Missile Operations and Support Cost
(FY 86 Dollars in Millions)

MDS MAJCOM	LGM-30 SAC
Unit Mission Personnel	$15.570
Unit Level Consumption	.856
Depot Maintenance	2.459
Sustaining Investment	6.748
Other Direct Costs	3.052
Installation Support Personnel	1.839
Indirect Personnel Support	4.538
Acquisition & Training	1.296
Total	36.358

Minuteman Typical Operating and Support Costs (FY 86 Dollars)
(reprinted from Table 7-5, AFR 173-13, 2 September 1986)

Minuteman Factor Summary
(FY 86 Dollars)

Code	Description	Life-Cycle Input Factors
F1	Missiles (Units Deployed)	50
F2	Primary Personnel-Officer	96
F3	Primary Personnel-Enlisted	413
F4	Primary Personnel-Civilian	1
F5	Operations Crew-Officer	52
F6	Operations Crew-Enlisted	0
F7	Operations Crew-Civilian	0
F8	Maintenance-Officer	8
F9	Maintenance-Enlisted	117
F10	Maintenance-Civilian	0
F11	Munitions-Officer	1
F12	Munitions-Enlisted	10
F13	Munitions-Civilian	0
F14	Communications-Officer	0
F15	Communications-Enlisted	13
F16	Communications-Civilian	0
F17	Security-Officer	4
F18	Security-Enlisted	219
F19	Security-Civilian	0
F20	Other Staff-Officer	31
F21	Other Staff-Enlisted	54
F22	Other Staff-Civilian	1
F23	Base Operating Support-Officer	1
F24	Base Operating Support-Enlisted	45
F25	Base Operating Support-Civilian	15
F26	Real Property Maintenance-Officer	0
F27	Real Property Maintenance-Enlisted	2
F28	Real Property Maintenance-Civilian	2
F28	Medical-Officer	1
F30	Medical-Enlisted	4
F31	Medical-Civilian	1
F32	Officer Pay	$55,422
F33	Enlisted Pay	$24,745
F34	Civilian Pay	$25,917
F40	Support Vehicle Fuel Cost per Missile	$2,607
F41	Maintenance Material Cost per Missile	$9,533
F42	Operations Material Cost per Missile	$4,983
F43	Depot Maintenance Repair Cost per Missile	$49,182
F44	Replenishment Spares Cost per Missile	$32,353
F45	Support Equipment Cost per Missile	$51,018
F46	Class IV Modification Cost per Missile	$24,875
F47	Software Support Cost per Missile	$26,720

Code	Description	Life-Cycle Input Factors
F48	Operational Test & Analysis Cost per Missile	$15,116
F49	Operational Test & Analysis Cost per Launch	$1,192,576
F50	Sustaining Engineering Cost per Missile	$30,649
F51	Lease Cost per Missile	$1,358
F52	Operational TDY Travel Cost per Missile	$918
F53	Other Contract Services Cost per Missile	$1,580
F54	Officer Weighted-Average Acquisition & Training Cost per Missile	$1,323
F55	Enlisted Weighted-Average Acquisition & Training per Cost Missile	$2,163
F56	Combat Crew Training School Cost per Graduate	$46,626
F60	Non-Rated Officer Turnover	.067
F61	Enlisted Turnover	.118
F62	Installation Support Non-Pay Cost per Person	$7,034
F63	Officer PCS (CONUS)	$1,513
F64	Enlisted PCS (CONUS)	$655
F65	Officer, Medical Non-Pay Benefit	$242
F66	Enlisted, Medical Non-Pay Benefit	$242
F67	Officer Acquisition Cost	$50,076
F68	Enlisted Acquisition Cost	$5,810
F69	Officer Specialty Training Cost	$9,592
F70	Enlisted Specialty Training Cost	$8,109
F91	Helicopter Support Costs	CORE

Appendix E
STRAMICE Cost Element Descriptions

Strategic Missile Cost Estimating (STRAMICE) Model
(reprinted from Section C, AFR 173-13, 2 September 1986)

(1) Unit Mission Personnel:

(a) Operations/Crew. The cost of pay and allowances for the full complement of missile operations crew and wing staff personnel required to operate the missile squadron or wing. Personnel are sub-divided into officer, enlisted, and civilian categories.

(b) Maintenance. The pay and allowances for personnel performing on and off equipment missile maintenance in support of assigned missiles, support equipment and unit-level training devices.

(c) Munitions. The pay and allowances for personnel performing maintenance and service functions involving missile munitions and nuclear armaments.

(d) Communications. The pay and allowances for personnel performing maintenance on missile communications system.

(e) Security. The pay and allowances for personnel required for squadron (wing) command forces and related administrative duties. Duties performed include entry control, close and instant boundary support, and security alert teams.

(f) Other Staff. The pay and allowances for other personnel assigned. It may include special civil engineering, transportation, or other personnel.

(2) Unit Level consumption

(a) Petroleum, Oil, and Lubricant (POL). The cost of ground fuels, missile propellants, and miscellaneous fuel, oil, and lubricants needed for unit operations for other than flying requirements.

(b) Maintenance Materials. The cost of expensed materials and equipment used in unit-level maintenance. This includes repairable and non repairable items that are not centrally managed with individual items reported, such as transistors, capacitors, gaskets, fuses, and other bit and piece material. It excludes repairables procured from the stock fund which are included in the replenishment spares cost element.

(c) Operational Materials. The cost of expensed materials and equipment used by non-maintenance unit activities. Examples include teletype paper, magnetic tapes, assault communication wire, chart, maps, binoculars, clocks, etc.

(3) Depot-Level Maintenance. The cost of Air Force Logistics Command personnel, material, and contractual services required to perform maintenance or modification of missiles, components, and support equipment. Work primarily is performed at centralized repair depots and contractor repair facilities, but also may be accomplished by mobile repair teams. Categories of depot cost by type of repair and subsystem include missile (overhaul, frame, propulsion) system; operations support equipment, launcher, missile accessories; guidance and control system; communications and control; and payload system. Also included is installation of Class IV modification kits.

(4) Sustaining Investment. The cost of procuring spares, Class IV modification kits and materials, support equipment, as well as the cost of creating and maintaining computer software.

(a) Replenishment Spares. The cost of replenishing the inventory of spares and repair parts that normally are repaired and returned to stock. The items primarily are procured to replace losses due to condemnations. In addition, this cost may include procurement of stock levels that are not provided by initial spares procurement.

(b) Replacement Support Equipment and Spares. The cost of replenishing the inventory of support equipment that is needed to operate or support missiles, missile subsystems, and other support equipment. This includes replacement of support equipment funded under the peculiar support portion of missile procurement (if the missile is out of production) and under common support (if the missile is out of production or the support equipment is common to more than one type of missile). Initial support equipment funded as common support equipment is excluded.

(c) Modification Kits. The cost of Class IV modification kits for missiles, support equipment, and training equipment. These modifications address retrofit changes that are required to achieve an acceptable level of safety; overcome mission capable deficiencies, improve reliability or reduce maintenance costs. Excluded are those modification that are undertaken to provide operational capability not called for in the original design or performance specifications.

(d) Software Support. The cost to develop and maintain computer software used to manage system data, evaluate system hardness, reliability, and nuclear surety, test engineering fault corrections and modify automatic test equipment (ATE) lest procedures. Also considered is update and modification of computer programs affecting targeting, and integration of strategic system.

(5) Other Direct Costs. The costs of other relevant and significant operating and support or direct logistics requirements for the missile not specifically included in other cost elements.

(a) Sustaining Engineering. The cost of organic and contract personnel and services to determine the integrity of material and services and to ensure and maintain operational reliability, to approve design changes, and to ensure their conformance with established specifications and standards. Includes contract engineering and technical services of liaison advice, and training concerning the installation, operation, maintenance, and logistical support of the missile. Engineering costs in support of software development and modification are excluded here as they are addressed separately within sustaining investment.

(b) Operational Test and Analysis. The cost for launch support (supplies and materials, ground fuels, expensed equipment, purchased maintenance of equipment, TDY travel and per diem) of operational test firing of missiles, range operations services and support, and evaluation and analysis of flight test data.

(c) Lease Costs. The cost for lease of administrative motor vehicles, office, and civil engineering equipment, and long line commercial communication systems and networks.

(d) Operational TDY and Per Diem. The cost of operational TDY travel and per diem for administrative and mission support of the missile.

(e) Second Destination Transportation. The cost of transporting the missile, major missile end items, missile subassemblies, and components between depot maintenance facilities, operational units, and stock points. The cost includes moving the missiles by air, rail or ground to launch sites for operational tests.

(f) Aircraft Support Costs. The cost of personnel, materials, and services required to provide helicopter surveillance and emergency transportation between host base, launch, and launch control facilities. Costs can be estimated using the CORE model and standard aircraft operations and support costs available in AFR 173-13.

(g) Other Contract Services. The costs of services not addressed elsewhere. Considers purchased maintenance of equipment, contract automated data processing services, contract logistics support, and miscellaneous contract services in support of missile operations and maintenance.

(6) Installation Support Personnel. Personnel not directly assigned to the unit but required for the unit to perform its mission in peacetime. As a rule, these personnel are assigned to the host organization at the installation and would not be required if the unit moved elsewhere.

(a) Base Operating Support (BOS). The cost of personnel supporting the operation of the installation and the tenant organizations stationed there. These personnel primarily are involved in the functions of communications, supply, services, security police (excluding system security), and transportation. It also includes a portion of higher headquarters not charged to mission elements, such as accounting, finance, and civilian and military personnel. Higher headquarters commander and operations staff are excluded.

(b) Real Property Maintenance (RPM). The cost of personnel assigned to the maintenance and operation of real property facilities and related management and engineering support work and services.

(c) Medical. The cost of medical personnel needed to support the unit at its peacetime location.

(7) Indirect Support of Personnel (Installation Support NonPay):

(a) Real Property Maintenance (Program Element xxx94). Real property maintenance is the variable nonpay cost of acquisition, construction, maintenance, and operation of real property facilities. The element includes costs for related management, engineering, and other support work and services. It includes costs for rent, supplies and equipment for the maintenance and repair of real property facilities (or structures furnished in lieu of real property), supplies or contract costs for additions, expansions, conversions, and other minor construction performed by the base civil engineer. The element also includes the procurement, supply, and related costs of production and distribution of basic utility services (electric, heating, air-conditioning, and water); purchased services; and administrative support for other engineering activities such as fire prevention, snow removal, and crash rescue. The element does not include construction of facilities financed by military construction program funds.

(b) Communications Support (Program Element xxx95). Communications support is the peculiar support equipment, necessary facilities, and the associated marginal costs specifically identified to base telephone systems, nontactical radio systems, wire communication services, intrabase radio systems, and base-level commercial communications requirements. The element does not include costs of AUTOVON, AUTODIN, and leased long line communication services.

(c) Nonpay Base Operating and Support (Program Element xxx96). This element includes support equipment, necessary facilities, and the associated nonpay variable costs specifically identified to base-level support functions for fixed installations and assigned mission units. This includes costs for supply, travel, automatic data processing support (nonfunctional), rent and other costs associated with comptroller, consolidated base personnel office, audiovisual services, social actions, judge advocate, command section (not MAJCOM), fuels management, and other base-support functions. The element also includes costs for Army and Air Force Exchange Service (as allowed in AFR 172-1, volume I) and commissary administration and management activities.

(8) Acquisition and Training:

(a) Officer Personnel. The Weighted Average Cost of formal skills training provided to primary program element and support officer personnel assigned to the missile system. Cost includes acquisition and basic military training.

(b) Enlisted Personnel. The Weighted Average Cost of formal skills training provided to primary program element and support officer personnel assigned to the missile system. Cost includes acquisition and basic military training.

(c) Combat Crew Training Squadron. The cost of missile-unique formal training provided by SAC to missile crew members.

Appendix F
Revised STRAMICE Model

Cost Element	Algorithm
1. Unit Mission Personnel	
1.1 Operations/Crew	
1.1.1 Military	(F5xF32+F6xF33)
1.1.2 Civilians	(F7xF34)
1.2 Maintenance	
1.2.1 Military	(F8xF32+F9xF33)
1.2.2 Civilian	(F10xF34)
1.3 Munitions	
1.3.1 Military	(F11xF32+F12xF33)
1.3.2 Civilian	(F13xF34)
1.4 Communications	
1.4.1 Military	(F14xF32+F15xF33)
1.4.2 Civilian	(F16xF34)
1.5 Security	
1.5.1 Military	(F17xF32+F18xF33)
1.5.2 Civilian	(F19xF34)
1.6 Other Staff	
1.6.1 Military	(F20xF32+F21xF33)
1.6.2 Civilian	(F22xF34)
2. Unit Level Consumption	
2.1 Fuel POL	(F1xF35)
2.2 Maintenance Materials	(F1xF36)
2.3 Operations Materials	(F1xF37)
3. Depot Maintenance (1)	
3.1 Missile	(F60xF61xF62)
3.2 Guidance	(F1x8766/F63)xF64xF65
3.3 Support & Launch	(F1x8766/F66)xF67xF68
3.4 Surface Command & Control	(F1x8766/F69)xF70xF71
3.5 Payload	(F1xF72)
3.6 Software	(F1xF73)
3.7 CLS (Trainer Maintenance)	(F1xF74)
3.8 Other (DPEM)	(F1xF75)
4. Sustaining Investment	
4.1 Replenishment Spares (3400)	(F1xF38)
4.2 Replacement Support Equipment	(F1xF39)
4.3 Class IV Modifications (3020)	(F1xF40)
4.4 Software Support	(F1xF41)

Cost Element	Algorithm
5. Other Direct Costs	
5.1 Operational Test & Analysis	(F43xF76)
5.2 Sustaining Engineering	(F1xF44)
5.3 Lease	(F1xF45)
5.4 Operational TDY Travel	(F1xF46)
5.5 2nd Destination Transportation and Helicopter Support	(F1xF77)
5.6 Other Contract Services	(F1xF47)
6. Installation Support Personnel	
6.1 Base Operating Support	
6.1.1 Military	(F23xF32+F24xF33)
6.1.2 Civilian	(F25xF34)
6.2 Real Property Maintenance	
6.2.1 Military	(F26xF32+F27xF33)
6.2.2 Civilian	(F28xF34)
6.3 Medical	
6.3.1 Military	(F29xF32+F30xF33)
6.3.2 Civilian	(F31xF34)
7. Indirect Personnel Support	
7.1 Installation Support, Non-Pay	(F2+F3+F23+F24+F26+ +F27+F29+F30)xF51
7.2 Medical O&M, Non-Pay	
7.2.1 Officer	(F2+F23+F26+F29)xF54
7.2.2 Enlisted	(F3+F24+F27+F30)xF55
7.3 PCS	
7.3.1 Officer	(F2+F23+F26+F29)xF52
7.3.2 Enlisted	(F3+F24+F27+F30)xF53
8. Acquisition and Training	
8.1 Acquisition	
8.1.1 Officer	(F2+F23+F26+F29)xF49xF56
8.1.2 Enlisted	(F3+F24+F27+F30)xF50xF57
8.2 Specialty Training	
8.2.1 Officer	(F2+F23+F26+F29)xF49xF58
8.2.2 Enlisted	(F3+F24+F27+F30)xF50xF59
8.3 CCTS*	(F5xF48xF49)

Revised Minuteman III Factors for STRAMICE Model

F1	Missiles (Units Deployed)	500
F2	Primary Personnel-Officer	988
F3	Primary Personnel-Enlisted	4547
F4	Primary Personnel-Civilian	98
F5	Operations Crew-Officer	420
F6	Operations Crew-Enlisted	0
F7	Operations Crew-Civilian	0
F8	Maintenance-Officer	103
F9	Maintenance-Enlisted	1288
F10	Maintenance-Civilian	0
F11	Munitions-Officer	13
F12	Munitions-Enlisted	110
F13	Munitions-Civilian	0
F14	Communications-Officer	0
F15	Communications-Enlisted	143
F16	Communications-Civilian	0
F17	Security-Officer	52
F18	Security-Enlisted	2411
F19	Security-Civilian	0
F20	Other Staff-Officer	400
F21	Other Staff-Enlisted	595
F22	Other Staff-Civilian	98
F23	Base Support-Office	14
F24	Base Support-Enlist	472
F25	Base Support-Civilian	188
F26	Real Property Maintenance-Officer	0
F27	Real Property Maintenance-Enlisted	21
F28	Real Property Maintenance-Civilian	25
F29	Medical Support-Officer	14
F30	Medical Support-Enlisted	42
F31	Medical Support-Civilian	13
F32	Officer Pay	$69,978
F33	Enlisted Pay	$30,992
F34	Civilian Pay	$35,568
F35	Motor Vehicle Fuel per Missile	$3,203
F36	Maintenance Material per Missile	$11,711
F37	Operations Material per Missile	$6,122
F38	Replenishment Spares per Missile	$15,353
F39	Support Equipment per Missile	$11,959
F40	Class IV Modification per Missile	$16,495
F41	Software Support per Missile	$8,247
F42	Operational Test & Analysis per Missile	$18,570
F43	Operational Test & Analysis per Launch	$1,465,081
F44	Sustaining Engineering per Missile	$134,305
F45	Lease Expenses per Missile	$1,668
F46	Operational TDY Travel per Missile	$1,096
F47	Other Contract Services per Missile	$1,941
F48	CCTS* Cost per Graduate	$55,662
F49	Non-Rated Officer Turnover	0.072

Revised Minuteman III Factors for STRAMICE Model

F50	Enlisted Turnover	0.116
F51	Installation Support Non-Pay	$8,397
F52	Officer PCS (CONUS)	$1,838
F53	Enlisted PCS (CONUS)	$595
F54	Officer, Medical Non-Pay	$431
F55	Enlisted, Medical Non-Pay	$431
F56	Officer Acquisition	$73,818
F57	Enlisted Acquisition	$4,674
F58	Officer Specialty Training	$17,587
F59	Enlisted Specialty Training	$10,016
F60	Annual Missile Repair Workload	12
F61	Missile Logistics Factor	1.11
F62	Missile Repair Cost	$117,944
F63	Guidance System MTBF	12,000
F64	Guidance System Logistics Factor	1.17
F65	Guidance System Repair Cost	$40,000
F66	Support & Launch MTBF	4900
F67	Support & Launch Logistics Factor	1.11
F68	Support & Launch Cost per Repair	$23,275
F69	Surface Command & Control MTBF	594
F70	Surface C&C Logistics Factor	1.11
F71	Surface C&C Cost per Repair	$377
F72	Annual Payload Maintenance per Missile	$15,052
F73	Annual Software Maintenance per Missile	$2,062
F74	Annual Trainer Maintenance per Missile	$10,928
F75	Annual DPEM Cost per Missile	$40,266
F76	Test Launches per Year	4
F77	2nd Destination Transportation and Helicopter Support per Missile	$14,029

*CCTS: Combat Crew Training School

Revised STRAMICE
Minuteman III O&S Estimate

	Cost Element	Annual O&S Dollars in Millions
1	Unit Mission Personnel	$213.545
2	Unit Level Consumption	$10.518
3	Depot Maintenance	$79.016
4	Sustaining Investment	$26.027
5	Other Direct Costs	$82.380
6	Installation Sup. Personnel	$26.578
7	Indirect Personnel Support	$58.724
8	Acquisition & Training	$8.155
	TOTAL:	$504.943

Two-Stage Minuteman Factors

F1	Missiles (Units Deployed)	500
F2	Primary Personnel-Officer	988
F3	Primary Personnel-Enlisted	4547
F4	Primary Personnel-Civilian	98
F5	Operations Crew-Officer	420
F6	Operations Crew-Enlisted	0
F7	Operations Crew-Civilian	0
F8	Maintenance-Officer	103
F9	Maintenance-Enlisted	1288
F10	Maintenance-Civilian	0
F11	Munitions-Officer	13
F12	Munitions-Enlisted	110
F13	Munitions-Civilian	0
F14	Communications-Officer	0
F15	Communications-Enlisted	143
F16	Communications-Civilian	0
F17	Security-Officer	52
F18	Security-Enlisted	2411
F19	Security-Civilian	0
F20	Other Staff-Officer	400
F21	Other Staff-Enlisted	595
F22	Other Staff-Civilian	98
F23	Base Support-Office	14
F24	Base Support-Enlist	472
F25	Base Support-Civilian	188
F26	Real Property Maintenance-Officer	0
F27	Real Property Maintenance-Enlisted	21
F28	Real Property Maintenance-Civilian	25
F29	Medical Support-Officer	14
F30	Medical Support-Enlisted	42
F31	Medical Support-Civilian	13
F32	Officer Pay	$69,978
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F36	Maintenance Material per Missile	$11,711
F37	Operations Material per Missile	$6,122
F38	Replenishment Spares per Missile	$15,353
F39	Support Equipment per Missile	$11,959
F40	Class IV Modification per Missile	$16,495
F41	Software Support per Missile	$8,247
F42	Operational Test & Analysis per Missile	$18,570
F43	Operational Test & Analysis per Launch	$1,465,081
F44	Sustaining Engineering per Missile	$134,305
F45	Lease Expenses per Missile	$1,668
F46	Operational TDY Travel per Missile	$1,096
F47	Other Contract Services per Missile	$1,941
F48	CCTS Cost per Graduate	$55,662
F49	Non-Rated Officer Turnover	0.072

Two-Stage Minuteman Factors

F50	Enlisted Turnover	0.116
F51	Installation Support Non-Pay	$8,397
F52	Officer PCS (CONUS)	$1,838
F53	Enlisted PCS (CONUS)	$595
F54	Officer, Medical Non-Pay	$431
F55	Enlisted, Medical Non-Pay	$431
F56	Officer Acquisition	$73,818
F57	Enlisted Acquisition	$4,674
F58	Officer Specialty Training	$17,587
F59	Enlisted Specialty Training	$10,016
F60	Annual Missile Repair Workload	8
F61	Missile Logistics Factor	1.11
F62	Missile Repair Cost	$117,944
F63	Guidance System MTBF	20,000
F64	Guidance System Logistics Factor	1.32
F65	Guidance System Repair Cost	$45,000
F66	Support & Launch MTBF	4900
F67	Support & Launch Logistics Factor	1.11
F68	Support & Launch Cost per Repair	$23,275
F69	Surface Command & Control MTBF	594
F70	Surface C&C Logistics Factor	1.11
F71	Surface C&C Cost per Repair	$377
F72	Annual Payload Maintenance per Missile	$15,052
F73	Annual Software Maintenance per Missile	$2,062
F74	Annual Trainer Maintenance per Missile	$10,928
F75	Annual DPEM Cost per Missile	$40,266
F76	Test Launches per Year	4
F77	2nd Destination Transportation and Helicopter Support per Missile	$14,029

Revised STRAMICE
Two-Stage Minuteman O&S Estimate

	Cost Element	Annual O&S Dollars in Millions
1	Unit Mission Personnel	$213.545
2	Unit Level Consumption	$10.518
3	Depot Maintenance	$74.416
4	Sustaining Investment	$26.027
5	Other Direct Costs	$82.380
6	Installation Sup. Personnel	$26.578
7	Indirect Personnel Support	$58.724
8	Acquisition & Training	$8.155
	TOTAL:	$500.344

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VITA

First Lieutenant Brian D. Joyce was born on 1 December 1961 in Kenosha, Wisconsin. He graduated from Tremper High School of Kenosha in 1979. Lieutenant Joyce enlisted in the U.S. Air Force later that same year. In 1985 he was selected to attend Purdue University under the Air Force Airmen Education and Commissioning Program. He graduated from Purdue in May 1988 with a Bachelor of Science degree in Aeronautical/Astronautical Engineering (BSAAE) and received his commission in the United States Air Force in September that same year.

Lieutenant Joyce was assigned to the F-15 Combined Test Force at Edwards AFB, California in October of 1988 where he served as a Flight Test Engineer responsible for formulating, planning, conducting, and reporting on the results of F-15E terrain following testing.

In May 1991, Lieutenant Joyce entered the School of Systems and Logistics at the Air Force Institute of Technology as a graduate Cost Analysis student.

Permanent Address: 1277 Eileen Drive
Beavercreek, Ohio 45434

Captain Patrick E. Poppert was born on 17 November 1963 in Lincoln, Nebraska. He attended Clover Park High School in Tacoma, Washington and entered the U.S. Air Force Academy in 1982, upon graduation. In 1986, Captain Poppert was awarded a Bachelor of Science in General Studies from the Academy. He was assigned to Patrick AFB as an internal auditor in 1987. As an auditor, he conducted comprehensive management evaluations of complex space center and test range operations at Patrick AFB and Cape Canaveral AFS, Florida. He also conducted performance appraisals for the 347th Tactical Fighter Wing operational and support missions at Moody AFB, Georgia.

While in Florida, Captain Poppert attended graduate and undergraduate school at night. He earned his MBA in Aviation Management from Embry-Riddle Aeronautical University, Florida in 1989. In 1990, he was awarded the professional designation of Certified Internal Auditor (CIA) from the Institute of Internal Auditors after successful completion of the CIA examination. In 1991, Captain Poppert received a second bachelors degree, with honors, in Accounting from Rollins College, Florida. Upon completion of this degree, he was recognized as the Rollins "Outstanding Accounting Student."

In May 1991, Captain Poppert entered the School of Systems and Logistics, Air Force Institute of Technology, as a graduate Cost Analysis student.

Permanent Address: 13544 Old Highway 99 Southeast
Tenino, Washington 98589

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13. ABSTRACT (Maximum 200 words)

This study analyzes proposed ICBM modifications from a life-cycle cost perspective. The proposals call for replacement of the Minuteman III second and third stage motors through a new, high performance single stage, without compromise in missile performance capabilities. This project was initiated by the Phillips Laboratory Applications Engineering Division. To expedite research and provide a basis for comparison, Phillips Laboratory also tasked graduate engineering students from the Air Force Institute of Technology (AFIT) School of Systems with a parallel design project. As graduate students of the AFIT School of Logistics, the authors of this study were solicited to provide life-cycle cost estimates for both alternatives. The Solid Technology Assessment and Cost Evaluation Model (STACEM) was selected to derive the estimates for program design, development, test and evaluation (DDT&E), and production costs. The Strategic Missile Cost Estimating (STRAMICE) model was chosen to develop one operations and support (O&S) cost estimate for both designs. Estimated DDT&E and production costs for the Phillips Laboratory design were $990.0 million. The same costs for the AFIT design were $743 million. The twenty year O&S estimate under either design was $10,029 million; a savings of approximately $69.8 million over the status quo.

14. SUBJECT TERMS

Life Cycle Costs, Cost Models, ICBM Modifications, ICBM, Minuteman Modifications, Phillips Laboratory

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